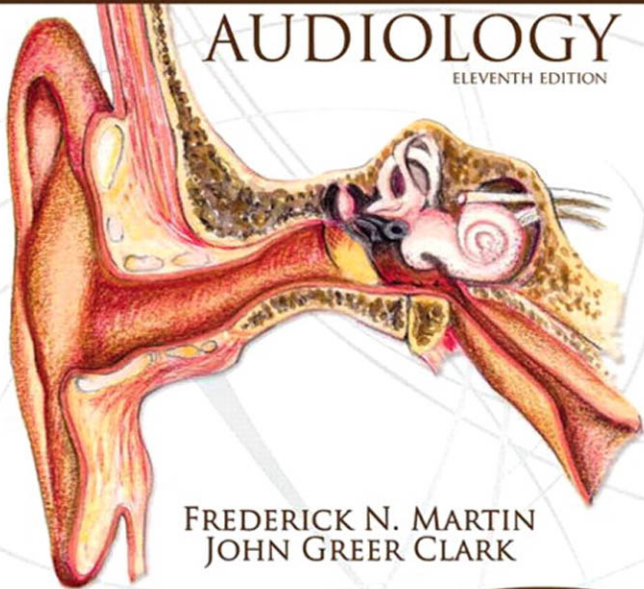


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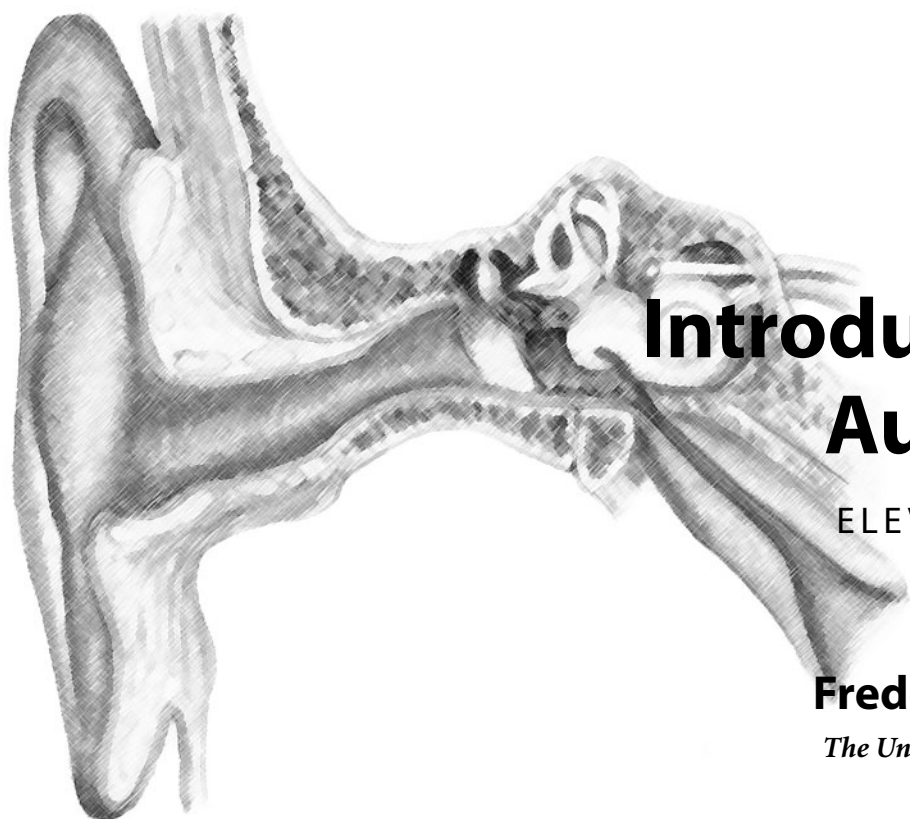
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Frederick N. Martin

The University of Texas at Austin

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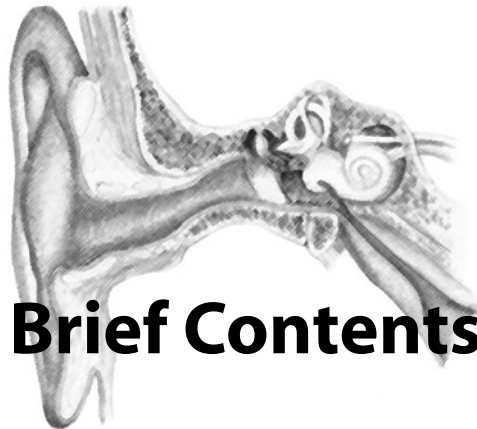
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To Cathy, my wife and best friend for more than half a century, for her support, encouragement, and love. To my son, David, a physician who takes to the practice of anesthesiology a sensitivity that is sometimes lacking. To my daughter, Leslie Anne, a professional in human resources whose talents include a large measure of humanity, and who is a wonderful and sweet friend. To my dear friend and colleague, Dr. Mark Ross, for his many contributions to audiology. To my students, who made mine a marvelous career. Finally, to my magnificent dogs, Fearless-Bluedog and Gaia, who fill my life with joy, and to the memories of Decibelle and Compass Rose, whose presence on this earth blessed every day.

FNM

To Kitty, my first and favorite editor, good friend and mother, to my students who continue to challenge and teach me, and to my wife, Suzanne, and our children who make everything worthwhile.

JGC



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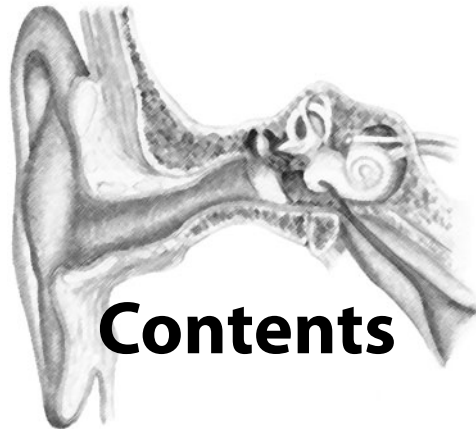
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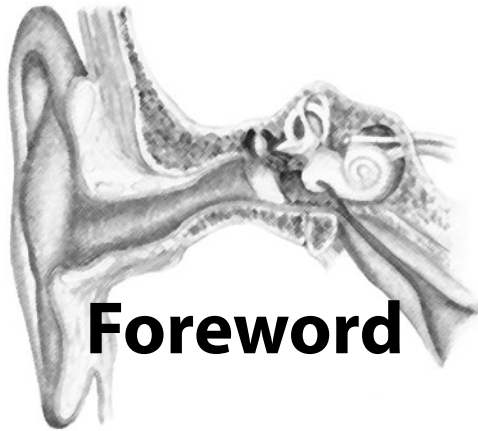
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Foreword

Mark Ross, Ph.D.

Professor Emeritus

University of Connecticut

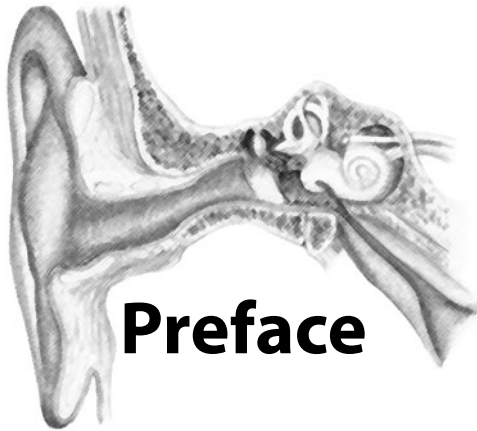
Writing the foreword of the 11th edition of any book is likely to be a challenge, particularly for the person who wrote the foreword to the two previous editions. As I reread what I wrote then, it seemed to me that everything I said at the time applies equally to this edition. A foreword, unlike the content of a text, is simply an introduction. And how many ways can one make an introduction? Of course, insofar as the content is concerned, the authors have clearly updated and upgraded their material as well as having made it even more user friendly than it was previously. All of this is no less than what I would expect from them. But as I consider the evolution of their content and approach from the first edition to this one, I do have a few thoughts that I would like to share with those who are using this text as their introduction to the profession of audiology.

The first edition of this book appeared in 1975 (but was begun in 1972). It is a text that I used when I last taught an introductory course in audiology. As I consider the content of this latest edition, it is apparent that one can track the development of the profession of audiology by comparing its content with that of the succeeding editions—not just the material and depth with which it is covered, but the learning adjuncts, such as the interactive companion website, which accompanies this text. In 1975 it was difficult enough to find any kind of appropriate text, much less one that vitalized the learning tasks with such creative visual and interactive materials. At the time, we stumbled along doing the best we could with the tools and knowledge we had available. We can see here, in the eleven appearances of this text, evidence of just how far we have progressed as a profession. The insights and knowledge we have now would have been almost inconceivable 35 years ago. From a profession whose name was largely unknown to the public, we have morphed into a full-fledged mature career, one that is known and accepted not only by the public, but also by many state and national agencies.

As the title indicates, this book will introduce students to the very latest that the field of audiology has to offer. Many students now using this text probably have not made up their minds whether they will pursue their studies in audiology or not. They may still be considering various options on which career path to pursue. It is a serious decision; certainly, one of the more important ones that a person can make. I would advise them to carefully examine the contents

of this book as they reflect on their decisions. Learning the material is not just a question of passing some examinations, but whether the content, or some portion of it, somehow “speaks” to them. The scope of the field is vast, from research into the basic auditory processes to the clinical applications of this knowledge. If you enjoy the laboratory setting, enjoy the challenge of creating new insights into how we hear, the profession has a place for you. If, on the other hand, you enjoy working with human beings and would find satisfaction being in a helping profession, then there is also a place for you as an audiologist. And there is a vast range of applications between these two interacting poles.

When Dr. Martin and I as fellow students and friends entered this field, it was a bit of a shot in the dark (and I am sure this applies to Dr. Clark as well, but later). We really did not know what we were getting into, in part because we did not have a text like this to guide us. All we knew was that we had to earn a living, and that there were jobs available then as speech pathologists and audiologists. But even though made in ignorance, it has turned out to be one of the wisest decisions that the two of us ever made. Readers of this text will have a more intelligent basis for making their decision. There is, as will be evident in the following pages, enough scope to meet a broad set of personal preferences, from various work settings to different kinds of daily tasks and challenges. It is a profession that will engage and challenge you intellectually and emotionally; it is more than a job; it is a lifelong mission. The prospect is ahead of you. Enjoy!



Preface

The founders of audiology could not have envisioned the many ways in which this profession would evolve to meet the needs of children and adults with hearing and balance disorders. Breakthroughs continue to come in all areas of audiological diagnosis and treatment, resulting in a profession that is more exciting and rewarding today than ever before.

Since treatment is the goal of audiology, and that is impossible without diagnosis, some people have developed the erroneous opinion that audiology is all about doing hearing tests. Surely, testing the hearing function is essential; however, it might appear that many tests could be performed by technical personnel who lack the education required to be total hearing health-care managers. Historically, the profession has rejected this approach and has developed a model wherein one highly trained, self-supervised audiologist carries the patient and family from history taking through diagnosis and into management. Toward this end, the development of a humanistic, patient professional, relationship-centered approach to hearing care has evolved, in which the audiologist guides patients and families to the highest success levels possible.

The profession has moved away from a required master's degree to the Doctor of Audiology (AuD) as the entry-level degree for those wishing to enter the profession of audiology. This is, in part, due to recognition of the fact that additional education and training are necessary for those practicing audiology, in order to meet the demands of an expanding scope of practice and continuing technological growth.

New to This Edition

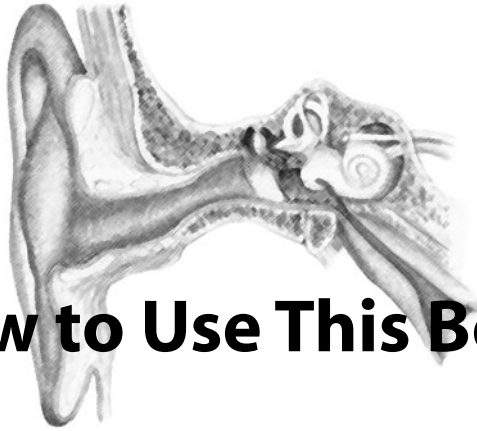
With each new edition of this book we strive not only to update the material to keep content current with recent research, but also to make it more user-friendly for students. Although a great deal of advanced material has been added, the primary target of this book continues to be the new student in audiology. While providing an abundance of how-to information, every effort is made to reveal to the tyro that audiology can be a rewarding and fascinating career. In this edition a number of new features have been added, including:

- An entire chapter devoted to clinical masking.
- A feature called “Assess as You Progress,” which places questions over content in the margins with answers at the bottoms of the pages so that readers can test their knowledge of new information as they read.

- A large variety of relevant websites placed at the ends of most chapters to provide a springboard for further investigation of an assortment of topics.
- An expansion of the Evolving Case Studies.
- Two new videos on the Companion Website.
- Updated and expanded Professional Resources on the Companion Website.
- Updated references to reflect the most recent research.

Throughout its history of three and a half decades, this book has been used by individuals in classes ranging from introductory to advanced levels. Students who plan to enter the professions of audiology, speech-language pathology, and education of children with hearing loss have used it. All of these individuals are charged with knowing all they can learn about hearing disorders and their ramifications. To know less is to do a disservice to those children and adults who rely on professionals for assistance.

The authors would like to express their appreciation to Lauren Murray for her contribution by assisting in the assemblage of the list of referenced websites. The authors would also like to express their appreciation to the reviewers of this edition: Colleen McAleer, Clarion University; Karen McNealy, Marshall University; and Suzanne Thompson, Iona College.



How to Use This Book

The chapter arrangement in this book differs somewhat from most audiology texts in several ways. The usual approach is to present the anatomy and physiology of the ear first, and then to introduce auditory tests and remediation techniques. After an introduction to the profession of audiology, this book first presents a superficial look at how the ear works. With this conceptual beginning, details of auditory tests can be understood as they relate to the basic mechanisms of hearing. Thus, with a grasp of the test principles, the reader is better prepared to benefit from the many examples of theoretical test results that illustrate different disorders in the auditory system. Presentations of anatomy and physiology, designed for greater detail and application, follow the descriptions of auditory disorders.

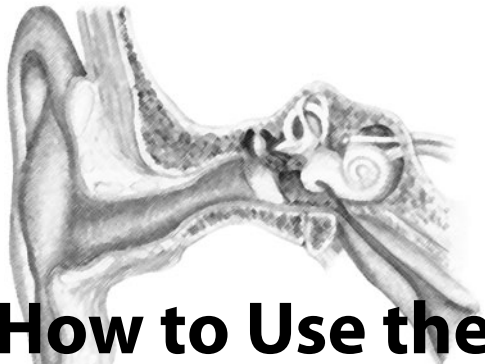
The organization of this book has proved useful because it facilitates early comprehension of what is often perceived as difficult material. Readers who wish a more traditional approach may simply rearrange the sequence in which they read the chapters. Chapters 9 through 12, on the anatomy, physiology, disorders, and treatments of different parts of the auditory apparatus, can simply be read before Chapters 4 through 8 on auditory tests. At the completion of the book the same information will have been covered.

The teacher of an introductory audiology course may feel that the depth of coverage of some subjects in this book is greater than desired. If this is the case, the primary and secondary headings allow for easy identification of sections that may be deleted. If greater detail is desired, the suggested reading lists at the end of each chapter can provide more depth. The book may be read in modules, so that only specified materials are covered.

Each chapter in this book begins with an introduction to the subject matter and a statement of instructional objectives. Liberal use is made of headings, subheadings, illustrations, and figures. A summary at the end of each chapter repeats the important portions. Terms that may be new or unusual appear in **boldface** print and are defined in a glossary at the end the text, thus eliminating the reader's need to underscore or highlight important words or concepts. In addition, review tables summarize the high points within many chapters. Readers wishing to test their understanding of different materials may find the questions at the end of each chapter useful for checking their grasp of new information. A new feature has been added for this edition called *Assess as You Progress*. Students will find questions in the margins relevant to the most-recently read material. Correct answers to these questions are given at the bottom of the page on which the questions appear. For those who wish to test their ability to synthesize what they learn and solve some practical clinical problems, the "Evolving Case Studies" sections in selected

chapters provide this opportunity. Also new to this edition is a large variety of relevant websites placed at the ends of most chapters. Access to these websites should help students in their grasp of material as well as provide a springboard for further investigation of a variety of topics.

The indexes at the back of this book are intended to help readers to find desired materials rapidly. In the Author Index, page numbers in *italics* direct the reader to complete book or journal references by a particular author.



How to Use the Companion Website

www.pearsonhighered.com/martinclark

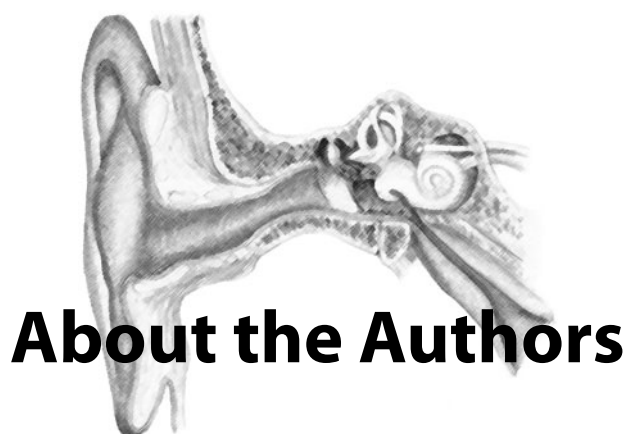
 **T**he *Introduction to Audiology Companion Website* (www.pearsonhighered.com/martinclark) has been designed to help students and new audiologists to assess their knowledge of the basic concepts of audiology through a variety of approaches. This Companion Website is designed to provide supplemental learning to class lectures and reading assignments, as well as to allow students to test their knowledge by completing specific interactive exercises. The contents of this Companion Website will prove useful to those enrolled in both introductory and intermediate audiology classes as well as those taking comprehensive examinations. It is also helpful in preparing for major tests such as national examinations required of both audiologists and speech-language pathologists for either state licensure or professional certification.

The Companion Website (CW) is divided into the following five sections:

1. **Learning Supplements.** This section provides both visual and auditory examples of topics presented in *Introduction to Audiology* and class lectures. These include
 - Anatomical Diagrams
 - Audiograms
 - Ear Pathology Slides
 - Hearing Aids and Assistive Listening Devices
 - Simulated Hearing Losses
2. **Professional Resources.** This section provides a compilation of forms, test instructions, clinic handouts, and more, that may prove useful to students in their current studies and their clinical endeavors following graduation. These include
 - Hearing Test Instructions
 - Ethics/Scope of Practice
 - Infection Control Guidelines
 - Patient Handouts
 - Abbreviations/Prefixes/Suffixes
 - Clinical Forms

3. **Interactive Assessment.** This section consists of a variety of exercises to facilitate learning of the associated contents of the parallel 15 chapters of the *Introduction to Audiology* textbook. Immediate feedback is provided on the appropriateness of responses, and answers are automatically cleared when exiting an exercise so that the student may revisit it for self-quizzing at a later date. If students are uncertain of the definitions of some of the terms within the exercises, they may review the corresponding material in the textbook. The definitions of terms can easily be located in the glossary at the end of the text, *Introduction to Audiology*. The better one's working vocabulary becomes, the better the chances of a successful understanding of audiology. Interactive exercises include
 - Matching
 - Multiple Choice
 - Outline Completion
 - Drag and Drop Activities
 - Crossword Puzzles
4. **Case Studies.** This section presents a series of studies, each including a theoretical patient's history and audiometric data. After reviewing this information, students may insert their decisions about the probable etiology of the disorder presented. Then, under "Case Management," they can insert how they would handle the case presented, to whom a referral might be made, what might be said or written in a report, and so forth. Then students can insert the reasons for their decisions. Case history and audiometric data may be revisited as needed. Once completed, students may click to see the correct diagnosis and compare their diagnostic and management decisions with the answers provided. If more information is required to make a diagnosis, one should read the appropriate chapter in *Introduction to Audiology*. The conditions presented in the case studies include
 - Acoustic neuroma
 - Central auditory lesion
 - Ménière's disease
 - Erroneous hearing loss
 - Otosclerosis
 - Serous effusion
 - And much more
5. **Clinical Demonstrations.** This section consists of a series of short videos depicting a variety of clinical activities or concepts. The video list includes
 - Earmold impression technique
 - Auditory brainstem response testing
 - Video otoscopy
 - Real ear measurements
 - Myringotomy
 - Otoacoustic emissions testing
 - And much more

It is our strong belief that use of this CW can be helpful in a variety of ways. It can assure users that they have mastered the materials being reviewed, guaranteeing confidence in preparation for examinations and other challenges. In its diagnostic form, it can instantly identify points of knowledge, weakness, or gaps to be filled, returning the user to source materials. This Companion Website should facilitate mastery of many of the topics covered in *Introduction to Audiology*.



About the Authors



Frederick N. Martin (Ph.D., The City University of New York) is Professor Emeritus in Communication Sciences and Disorders at The University of Texas at Austin where he served as the Lillie Hage Jamail Centennial Professor for 24 of his 38 years at The University. His specialty has been clinical audiology, and he has particular interests in the area of patient and parent counseling. Books authored by Dr. Martin include the first six editions of *Introduction to Audiology*, as well as the first four editions of *Introduction to Audiology: A Study Guide, Exercises in Audiometry, Clinical Audiometry and Masking*, and *Basic Audiometry*. Dr. Martin has also edited *Pediatric Audiology*, *Medical Audiology*, *Hearing Disorders in Children*, and the ten-volume series *Remediation of Communication Disorders*. He has co-edited two editions of *Communication Sciences and Disorders: From Science to Clinical Practice*. In addition, he has written 24 chapters for edited texts, 121 journal articles, and 102 convention or conference papers. During his tenure at The University of Texas, he received the Teaching Excellence Award of the College of Communication, the Graduate Teaching Award, and the Advisor's Award from the Texas Alumni Association. The National Student Speech Language Hearing Association named him Professor of the Year in Communication Sciences and Disorders for 2002–2003 at The University of Texas. He was the 1997 recipient of the Career Award in Hearing from the American Academy of Audiology and in 2006 was the first to receive the Lifetime Achievement Award from the Texas Academy of Audiology. His book, *Introduction to Audiology*, was a finalist for the prestigious Hamilton Book Award of The University of Texas in 2006. In 2009 he was honored by the Arkansas Hearing Society with the Thomas A. LeBlanc Award. He served as a reviewer for the most prominent audiology journals and for years co-edited *Audiology—A Journal for Continuing Education*.



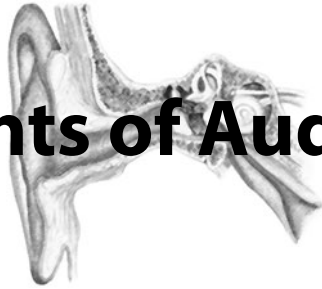
John Greer Clark (Ph.D., University of Cincinnati) is Assistant Professor in Communication Sciences and Disorders at the University of Cincinnati, an Ida Institute Faculty Fellow, a visiting professor at the University of Louisville, and president of Clark Audiology, LLC. He is co-editor of *Tinnitus and Its Management: A Clinical Text for Audiologists*, co-author of *Counseling in Audiologic Practice*, author of the professional guide, *Audiology for the School Speech-Language Clinician*, and the consumer guides, *The ABCs to Better Hearing*, *Say What?* and *Now What?* His more than 75 publications

cover a variety of aspects of communication disorders. Dr. Clark has received the Honors of the Ohio Speech and Hearing Association as well as both the Prominent Alumni and Distinguished Alumni Awards from the University of Cincinnati Department of Communication Sciences and Disorders. He is a past President of the Academy of Rehabilitative Audiology, past Chair of the American Board of Audiology, and served four years on the Boards of Directors for the Ohio Academy of Audiology and the American Academy of Audiology. A co-founder of the Midwest Audiology Conference, he has been an associate editor, editorial consultant, and reviewer for several professional journals.

Drs. Martin and Clark are both Fellows of the American Academy of Audiology and the American Speech-Language-Hearing Association. Together they have co-edited two academic texts: *Effective Counseling in Audiology: Perspectives and Practice* and *Hearing Care for Children*. In addition to their work together on the seventh through eleventh editions of *Introduction to Audiology* and the accompanying supplements, they have co-authored *Elements of Audiology*; the fifth edition of *Introduction to Audiology: A Review Manual*; *Audiology Instructor's e-Assistant* (a CD-ROM); and *Introduction to Audiology: A Teacher's Manual*; and they have collaborated on research for the periodical scientific literature. They also produced *Interactive Audiology*, a CD-ROM that provides instructional videos, case studies, and a wide variety of practice and learning exercises, much of which is now a part of the Companion Website that accompanies this book.

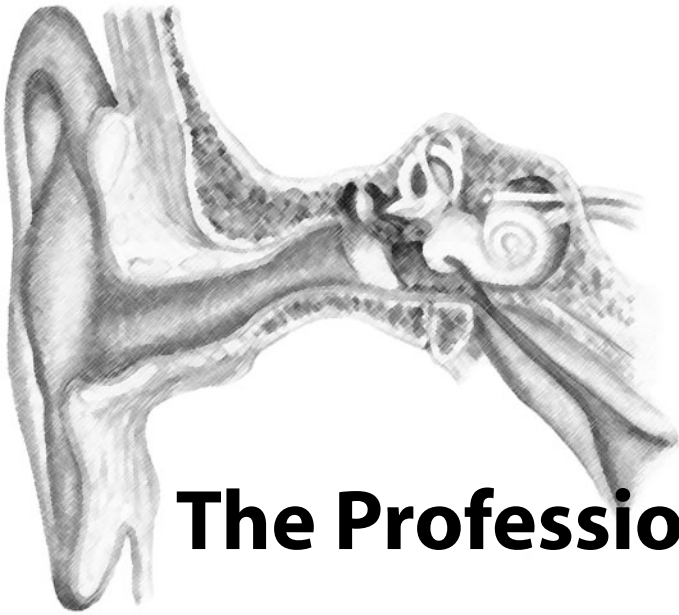
PART I

Elements of Audiology





The first part of this book requires no foreknowledge of audiology. Chapter 1 presents an overview of the profession of audiology, its history, and directions for the future. Chapter 2 is an elementary look at the anatomy of the auditory system to the extent that basic types of hearing loss and simple hearing tests can be understood. Oversimplifications are clarified in later chapters. Tuning-fork tests are described here for three purposes: first, because they are practiced today by many physicians; second, because they are an important part of the history of the art and science of audiology; and third, because they illustrate some fundamental concepts that are essential to understanding contemporary hearing tests. Chapter 3 discusses the physics of sound and introduces the units of measurement that are important in performing modern audiologic assessments. Readers who have had a course in hearing science may find little new information in Chapter 3 and may wish to use it merely as a review. For those readers for whom this material is new, its comprehension is essential for understanding what follows in this book.



The Profession of Audiology

THE PROFESSION OF AUDIOLOGY has grown remarkably since its inception only a little more than 50 years ago. What began as a concentrated effort to assist hearing-injured veterans of World War II in their attempts to reenter civilian life has evolved into a profession serving all population groups and all ages through increasingly sophisticated diagnostic and rehabilitative instrumentation. The current student of audiology can look forward to a future within a dynamic profession, meeting the hearing needs of an expanding patient base.

LEARNING OBJECTIVES

The purpose of this opening chapter is to introduce the profession of audiology, from its origins through its course of development to its present position in the hearing-healthcare delivery system. At the completion of this chapter, the reader should be able to

- Describe the evolution of audiology as a profession.
- Discuss the impact of hearing impairment on individuals and society.
- List specialty areas within audiology and the employment settings within which audiologists may find themselves.
- Describe the reasons that speech-language pathologists may closely interact with audiologists as they provide services within their chosen professions.



The Evolution of Audiology

Prior to World War II, hearing-care services were provided by physicians and commercial hearing aid dealers. Because the use of hearing protection was not common until the latter part of the war, many service personnel suffered the effects of high-level noise exposure from modern weaponry. It was the influx of these service personnel reentering civilian life that created the impetus for the professions of **otology** (the medical specialty concerned with diseases of the ear) and speech pathology (now referred to as **speech-language pathology**) to work together to form military-based **aural rehabilitation** centers.

1. Audiology developed from the professions of _____ and _____.

These centers met with such success that following the war many of the professionals involved in the programs' development believed that their services should be made available within the civilian sector. While it was primarily through the efforts of the otologists that the first rehabilitative programs for those with hearing loss were established in communities around the country, it was mainly those from speech-language pathology, those who had developed the audiometric techniques and rehabilitative procedures of the military clinics, who staffed the emerging community centers (Henoch, 1979).

Audiology developed rapidly as a profession distinct from medicine in the United States. While audiology continues to evolve outside of the United States, most professionals practicing audiology in other countries are physicians, usually otologists. Audiometric technicians in many of these countries attain competency in the administration of hearing tests; however, it is the physician who dictates the tests to be performed, and solely the physician who decides on the management of each patient. Some countries have developed strong academic audiology programs and independent audiologists like those in the United States, but, with the exception of geographically isolated areas, most audiologists around the globe look to American audiologists for the model of autonomous practice that they wish to emulate.

The derivation of the word *audiology* is itself unclear. No doubt purists are disturbed that a Latin root, *audire* (to hear), was fused with a Greek suffix, *logos* (the study of), to form the word *audiology*. It is often reported that *audiology* was coined as a new word in 1945 simultaneously, yet independently, by Dr. Raymond Carhart¹ and Norton Canfield, an otologist active in the establishment of the military aural rehabilitation programs. However, a course established in 1939 by the Auricular Foundation Institute of Audiology entitled "Audiological Problems in Education" and a 1935 instructional film developed under the direction of Mayer Shier titled simply *Audiology* clearly predate these claims (Skafta, 1990). Regardless of the origin of the word, an audiologist today is defined as an individual who, "by virtue of academic degree, clinical training, and license to practice and/or professional credential, is uniquely qualified to provide a comprehensive array of professional services related to . . . the audiologic identification, assessment, diagnosis, and treatment of persons with impairment of auditory and vestibular function, and to the prevention of impairments associated with them" (American Academy of Audiology, 2004).

2. A founder of audiology, often called the "father of audiology," is _____.

Academic Preparation in Audiology

In the United States, educational preparation for audiologists evolved as technology expanded, leading to an increasing variety of diagnostic procedures and an expanded professional scope of practice (American Academy of Audiology, 2004; American Speech-Language-Hearing

Association, 2004b). Audiology practices have grown to encompass the identification of hearing loss, the differential diagnosis of hearing impairment, and the nonmedical treatment of hearing impairment and balance disorders. What began as a profession with a bachelor's level preparation quickly transformed into a profession with a required minimum of a master's degree to attain a state license, now held forth as the mandatory prerequisite for clinical practice in most states. More than a quarter of a century ago, Raymond Carhart, one of audiology's founders, recognized the limitations imposed by defining the profession at the master's degree level (Carhart, 1975). Yet it was another 13 years before a conference, sponsored by the Academy of Dispensing Audiologists, set goals for the profession's transformation to a doctoral level (Academy of Dispensing Audiologists, 1988).

In recent years academic programs have transitioned to the professional doctorate for student preparation in audiology designated as the doctor of audiology (Au.D.). At most universities the Au.D. comprises 4 years of professional preparation beyond the bachelor's degree with heavy emphasis on didactic instruction in the early years gradually giving way to increasing amounts of clinical practice as students progress through their programs. The final (fourth) year consists of a full-time clinical placement usually in a paid position.

Although the required course of study to become an audiologist remains somewhat heterogeneous, course work generally includes hearing and speech science, anatomy and physiology, fundamentals of communication and its disorders, counseling techniques, electronics, computer science, and a range of course work in diagnostic and rehabilitative services for those with hearing and balance disorders. It is through this extensive background that university programs continue to produce clinicians capable of making independent decisions for the betterment of those they serve.

3. Two professional documents that govern the practice of audiology are _____ and _____.

4. The entry-level degree for the profession of audiology is the _____.

See the Professional Resources section of the Companion Website for the full text of AAA and ASHA audiology scopes of practice and codes of ethics.



Licensing and Certification

The practice of audiology is regulated in the United States through license or registration in every state of the union and the District of Columbia. Such regulation ensures that audiology practitioners have met a minimum level of educational preparation and, in many states, that a minimum of continuing study is maintained to help ensure competencies remain current. A license to practice audiology or professional registration as an audiologist is a legal requirement to practice the profession of audiology. Licensure and registration are important forms of consumer protection, and loss or revocation of this documentation prohibits an individual from practicing audiology. To obtain an audiology license, one must complete a prescribed course of study, acquire approximately 2,000 hours of clinical practicum, and attain a passing score on a national examination in audiology. The use of support personnel within a variety of practice settings is growing. The responsibilities of these "audiologist's assistants" have been delineated by the American Academy of Audiology (1997), and in some states are regulated through the state's licensing board.

5. The credential required for the practice of audiology in the United States is _____.

6. The two organizations most closely associated with audiology are _____ and _____.

In contrast to state licensure and registration, certification is not a legal requirement for the practice of audiology. Audiologists who choose to hold membership in ASHA are required by ASHA to hold the Certificate of Clinical Competence in Audiology attesting that a designated level of preparation as an audiologist has been met and that documented levels of continuing education are maintained throughout one's career. Many audiologists select certification from the American Board of Audiology as a fully voluntary commitment to the principles of lifelong continuing education. ABA certification is an attestation that one holds him- or herself to a higher standard than may be set forth in the legal documents of licensure or registration.

Licensing laws in nearly half of the states define permitted patient care assignments for audiology assistants. Assistants can be quite valuable in increasing practice efficiency and meeting the needs of a growing population with hearing loss. It is audiologists' responsibility to ensure that their assistants have the proper preparation and training to adequately perform assigned duties.

Prevalence and Impact of Hearing Loss

Although audiology had its birth under the aegis of the military, its growth was rapid within the civilian sector because of the general prevalence of hearing loss and the devastating impact that hearing loss has on the lives of those affected. The reported prevalence of hearing loss varies somewhat depending on the method of estimation (actual evaluation of a population segment or individual response to a survey questionnaire), the criteria used to define hearing loss, and the age of the population sampled. However, it is generally accepted that as the civilized world enters the second millennium there are more than 32 million Americans with hearing loss sufficient to adversely affect their lives (see Table 1.1).

The **prevalence** of hearing loss increases with age (Figure 1.1), and it has been estimated that the number of persons with hearing loss in the United States over the age of 65 years will reach nearly 13 million by the year 2015. The number of children with permanent hearing loss is far fewer than the number of adults. However, the prevalence of hearing loss in children is almost staggering if we consider those children whose speech and language development and academic performances may be impacted by mild transient ear infections so common among children. While not all children have problems secondary to ear pathologies, 90 percent of children in the United States will have at least one ear infection before 6 years of age (National Institute on Deafness and Other Communication Disorders, 1992).

TABLE 1.1 Prevalence of Hearing Loss and Related Disorders

50 million people have tinnitus (ear or head noises).
30 million people are regularly exposed to hazardous noise levels.
30 million people are hard of hearing.
10 million people have some degree of permanent noise-induced hearing loss.
2 million people are classified as deaf.
As many as 6 of every 1,000 children may be born with hearing impairment.
As many as 15% of school-age children may fail a school hearing screening mostly due to a transient ear infection.
Before the age of 6 years, 90% of children in the United States will have had at least one ear infection.

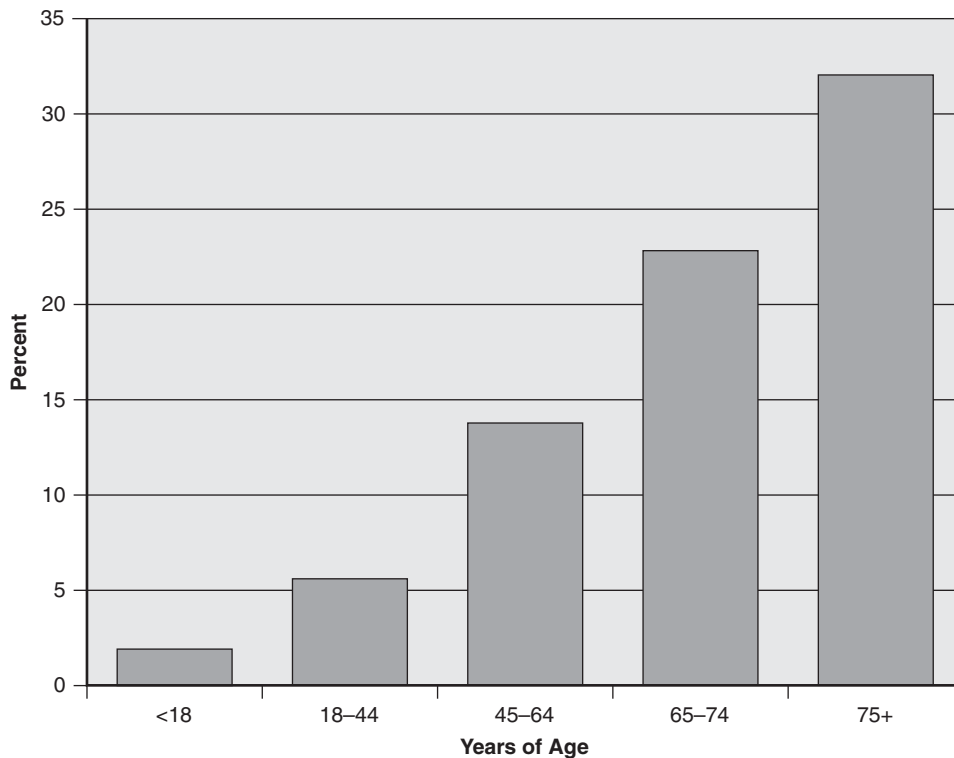


FIGURE 1.1 The percentage of individuals with a hearing loss relative to the general population. (Source: www.audiology.org/about/newsroom/atagance.php. June 16, 2004)

For those children with recurrent or persistent problems with ear infections, the developmental impact may be significant. Studies have shown that children prone to ear pathologies may lag behind their peers in articulatory and phonological development, in the ability to receive and express thoughts through spoken language, in the use of grammar and syntax, in the acquisition of vocabulary, in the development of auditory memory and auditory perception skills, and in social maturation (Clark & Jandl, 1996). There is indication, however, that children with early history of ear infections, while initially delayed in speech and language, may catch up with their peers by the second year of elementary school (Roberts, Burchinal, & Zeisel, 2002; Zumach, Gerrits, Chenault, & Anteunis, 2010). Even so, a study reporting no significant differences in speech understanding in noise between groups of third- and fourth-grade students with and without histories of early ear infections did, however, find a much greater range in abilities for those with a positive history of ear infections (Keogh et al., 2005). This study demonstrated that some of these children experience considerable difficulty in speech understanding.

The fact that many children with positive histories of ear infection develop no speech, language, or educational delays suggests that factors additional to fluctuating hearing abilities may also be involved in the learning process (Davis, 1986; Williams & Jacobs, 2009), but this in no way reduces the need for intervention. The impact of more severe and permanent hearing loss has an even greater effect on a child's developing speech and language and educational performance

7. True/False
Hearing loss in children is a concern only due to the possible impact on communication.

(Diefendorf, 1996) and also on the psychosocial dynamics within the family and among peer groups (Altman, 1996; Clark & English, 2004).

Often, the adult patient's reaction to the diagnosis of permanent hearing loss is as devastating as that of the caregivers of young children with newly diagnosed hearing impairment (Martin, Krall, & O'Neal, 1989). Yet the effects of hearing loss cannot be addressed until the reason for the hearing loss is diagnosed, and, left untreated, hearing loss among adults can seriously erode relationships both within and outside of the family unit. Research has demonstrated that among older adults hearing loss is related to overall poor health, decreased physical activity, and depression. Indeed, Bess, Lichtenstein, Logan, Burger, and Nelson (1989) demonstrated that progressive hearing loss among older adults is associated with progressive physical and psychosocial dysfunction.

In addition to the personal effects of hearing loss on the individual, the financial burden of hearing loss placed upon the individual, and society at large, is remarkable. More than 20 years ago, Grundfast and Carney (1987) estimated the total annual costs for the treatment of childhood ear infections alone to be as high as \$2 billion in the United States. When one adds to this figure the costs of educational programs and (re)habilitation services for those with permanent hearing loss and the lost income when hearing impairment truncates one's earning potential, the costs become staggering. Northern and Downs (1991) estimate that for a child of 1 year of age with severe hearing impairment and an average life expectancy of 71 years the economic burden of deafness can exceed \$1 million.

A survey conducted by the Better Hearing Institute of over 44,000 American families reported that those who are failing to treat their hearing problems are collectively losing at least \$100 billion in annual income (NAPS, 2007). While many people think of hearing loss as affecting mainly older individuals, most people with hearing loss are in the prime of their lives, including one out of six baby boomers ages 41 to 59 years. While the Better Hearing Institute study reported that the use of hearing aids can reduce the effects of lost income by nearly 50 percent, only one in four with hearing problems seek treatment.

A Blending of Art and Science

Audiology is a scientific discipline based upon an ever-growing body of research on the fundamentals of hearing, the physiologic and psychosocial impacts of lost hearing, and the technological aspects of both hearing diagnostics and pediatric and adult hearing-loss treatments. Over the years, caution has been expressed that audiology not become mired in the technological aspects of service delivery. Indeed, as Hawkins (1990) points out, the importance of the many technological advances seen in audiology may be of only minor importance to the final success with patients when compared to the counseling and rehabilitative aspects of audiological care.

The blending of the science of audiology with the art of patient treatment makes audiology a highly rewarding profession. It is the humanistic side of our professional endeavors that not only brings audiologists close to the patients and families they serve but makes the outcomes of provided services rewarding for both the practitioner and the recipient of care. All patients bring to audiology clinics their own life stories, personal achievements, and recognized (and unrecognized) limitations. Audiologists must learn to listen supportively, thereby allowing patients

8. True/False
Ear infections in children may or may not cause hearing loss.

9. List three areas that are impacted by hearing loss in adults besides hearing sensitivity.

Clinical Commentary

Speech-language pathologists often find that they work in close concert with audiologists. This may be true with children, whose hearing loss can have a direct impact on speech and language development, as well as with older adults, who have a higher incidence of age-related communication disorders. It is the frequent coexistence of hearing disorders and speech/language problems that has led the American Speech-Language-Hearing Association to include hearing-screening procedures, therapeutic aspects of audiological rehabilitation, and basic checks of hearing aid performance within the speech-language pathologist's scope of practice (ASHA, 2001, 2004a).

to tell their own stories, so that both diagnostics and rehabilitation may be effectively tailored to individual needs (Clark & English, 2004).

Audiology Specialties

Most audiology training programs prepare audiologists as generalists, with exposure and preparation in a wide variety of areas. Following graduation, however, many audiologists discover their chosen practice setting leads to a concentration of their time and efforts within one or more specialty areas of audiology. In addition, many practice settings and specialty areas provide audiologists with opportunities to participate in research activities to broaden clinical understanding and application of diagnostic and treatment procedures. When those seeking audiological care are young or have concomitant speech or language difficulties, a close working relationship of audiologists with professionals in speech-language pathology or in the education of those with hearing loss often develops.

It is the varied nature of the practice of audiology that can make an audiology career stimulating and rewarding. Indeed, the fact that audiologists view their careers as both interesting and challenging has been found to result in a high level of job satisfaction within the profession (Martin, Champlin, & Streetman, 1997). The 1999–2000 *Jobs Almanac* ranked audiology as the 34th-most-desirable profession in the United States out of 250 rated occupations. More recently, a *U.S. News and World Report* article ranked audiology as the top choice in the reporter's "excellent" career choice category (Nemko, 2006).

Medical Audiology

The largest number of audiologists are currently employed within a medical environment, including community and regional hospitals, physicians' offices, and health maintenance organizations. Audiologists within military-based programs, Veterans Administration medical centers, and departments of public health often work primarily within the specialty of medical audiology. Many of the audiology services provided within this specialty focus on the provision of diagnostic assessments to help establish the underlying cause of hearing or balance disorders (Figure 1.2). The full range of diagnostic procedures detailed in this book may be employed by the medical audiologist with patients of all ages. Results of the final audiological assessment are combined with the diagnostic findings of other medical and nonmedical professionals to yield a final diagnosis. Medical audiologists may also work within newborn-hearing-loss-identification programs and monitor the hearing levels of patients being treated with medications that can harm hearing. Additional responsibilities frequently include such nonmedical endeavors as hearing aid dispensing.



FIGURE 1.2 A computerized rotational chair allows the audiologist to attain a comprehensive evaluation of patients suffering with balance disorders. (Courtesy of Micromedical Technologies, 10 Kemp Drive, Chatham, IL 62629)

Educational Audiology

Following the federal mandates dictated by Public Law 94-142, the Education for All Handicapped Children Act, in 1975 and Public Law 99-457, the Education for the Handicapped Amendments, in 1986, the need for audiologists within the schools has increased. Yet, fewer than half the audiologists required to meet the needs of children in the public schools are serving in that capacity. Educational audiologists bear a wide range of responsibilities in minimizing the devastating impact that hearing loss has on the education of young children, and in the educational setting they may work closely with professionals in the education of deaf and hearing-impaired children and speech-language pathology. Audiologists in this specialty are responsible for the identification of children with hearing loss and referral for medical and other professional services as needed; the provision of rehabilitative activities including auditory training, speechreading, and speech conservation; the creation of hearing-loss-prevention programs; counseling and guidance about hearing loss for parents, pupils, and teachers; and the selection and evaluation of individual and group amplification (Blair, 1996).

Pediatric Audiology

Work with children and their families has perhaps more far-reaching effects than any other challenge audiologists undertake. In addition to developing a honed proficiency in the special

considerations involved with the diagnostic evaluation of young children, pediatric audiologists must be prepared to bring to their clinical endeavors an empathy that will help guide parents and families through what is an exceptionally difficult time in their lives. One of the pediatric audiologist's primary roles is facilitating parents' efforts to meet the many (re)habilitative challenges the child and family will face.

Nonaudiology professionals who work in the areas of communication and education for children with hearing loss will frequently work closely with pediatric audiologists. Audiologists within a variety of employment settings may work with children and their families. However, those within pediatric hospitals, large rehabilitation centers, and community-based hearing and speech centers will often see a higher percentage of the pediatric population.

Dispensing/Rehabilitative Audiology

Thirty-five years ago, ASHA rescinded its previous ban on the dispensing of hearing aids by audiologists. Since that time, audiologists have become increasingly active in the total hearing rehabilitation of their patients. (See Chapter 14.) While many audiologists establish their dispensing/rehabilitative practices within hospitals or physicians' offices, a growing number are attracted to the greater autonomy afforded by an independent practice within their communities.

Industrial Audiology

As discussed in Chapter 11, exposure to high levels of noise is one of the primary contributors to insidious hearing loss. Many of today's industries produce noise levels of sufficient intensity to permanently damage employees' hearing. According to the National Institute for Occupational Safety and Health (1996), more than 30 million U.S. workers are exposed to hazardous noise levels, resulting in noise-induced occupational hearing loss being the most common occupational disease. Allowable levels and duration of employee noise exposure have been set by the U.S. Department of Health. To ensure that adequate hearing protection is both provided by the employer and used effectively by the employee, audiologists who work in industry design hearing-conservation programs to identify and measure excessive noise areas, consult in the reduction of noise levels produced by industrial equipment, monitor employee hearing levels, educate employees on the permanent consequences of excessive noise exposure, and fit hearing protection for those employees with excessive exposure (Melnick, 1994). While some audiologists practice full time exclusively within industrial settings, most who work with industry provide these services as part-time contracted consultants, or as an adjunct to their work within other practice settings. As consultants to industry, audiologists may work in conjunction with attorneys, industrial physicians and nurses, industrial hygienists, safety engineers, and industrial relations and personnel officers within management and unions.

10. The work of audiologists in areas of noise is sometimes called _____.

Recreational and Animal Audiology

While some audiologists will find themselves working largely or wholly within other specialty areas of audiology, most who work within either recreational or animal audiology do so as a smaller part of their employment responsibilities. Chapter 11 details the deleterious effects of

FIGURE 1.3 The identification, diagnosis, and management of canine hearing loss should be carried out through a systematic protocol by qualified practitioners. Objective hearing assessments designed for humans as described in Chapter 7 can be completed successfully on dogs with mild sedation. (Courtesy of the Facility for the Education and Testing of Canine Hearing and the Laboratory for Animal Bioacoustics [FETCH-LAB], University of Cincinnati.)



intense sounds on human hearing. One must only wonder at the human proclivity to willingly place one's sense of hearing in harm's way. Yet, it is true that many activities, ranging from the enjoyment of music and the use of firearms to the growing recreational use of motorboats, snowmobiles, motorbikes, and race cars, can have a negative impact on human hearing. Recreational audiologists continue to find opportunities to provide hearing conservation services to those who enjoy excessively loud forms of recreation.

An even more recent, and smaller, specialty area in audiology lies in the audiological assistance given to non-human animals, particularly the canine, "man's best friend" (Figure 1.3). There are more than 80 breeds of dogs with documented congenital hearing loss, and many dogs experience the same age-related declines in hearing seen in humans. Certainly, concerns for canine safety arise in the presence of hearing loss. In addition, dogs with hearing loss residing in a home can become easily startled or frightened by a person's unexpected presence, placing young children particularly at risk. Counseling of dog owners on these issues is an important service provided by animal audiologists. Hearing conservation for service animals, especially military working dogs, is also a concern of animal audiologists and these dogs' owners considering the substantial time and money that is invested in the training of these animals. Ongoing research continues on effective hearing loss prevention and management for canines (www.fetchlab.org).

Employment Settings

While some audiologists list their primary employment function as a researcher, administrator, or university teacher, more than 82 percent consider themselves to be direct clinical service providers (AAA, 2010). As noted in Figure 1.4, more audiologists deliver services within a medical environment than within any other single employment setting. Private practice constitutes the second-largest employment affiliation for audiologists.

The trend of most students in master's degree programs to state a preference for employment within a medical setting may be giving way to Au.D. students' aspirations of future employment within private practice (Freeman & Doyle, 2001). By far the most rapidly growing employment setting for audiologists is that of private practice. Today, private-practice audiology concentrates on the dispensing/rehabilitative efforts of the audiologist; however, a number of practices offer a wide array of diagnostic services as well.

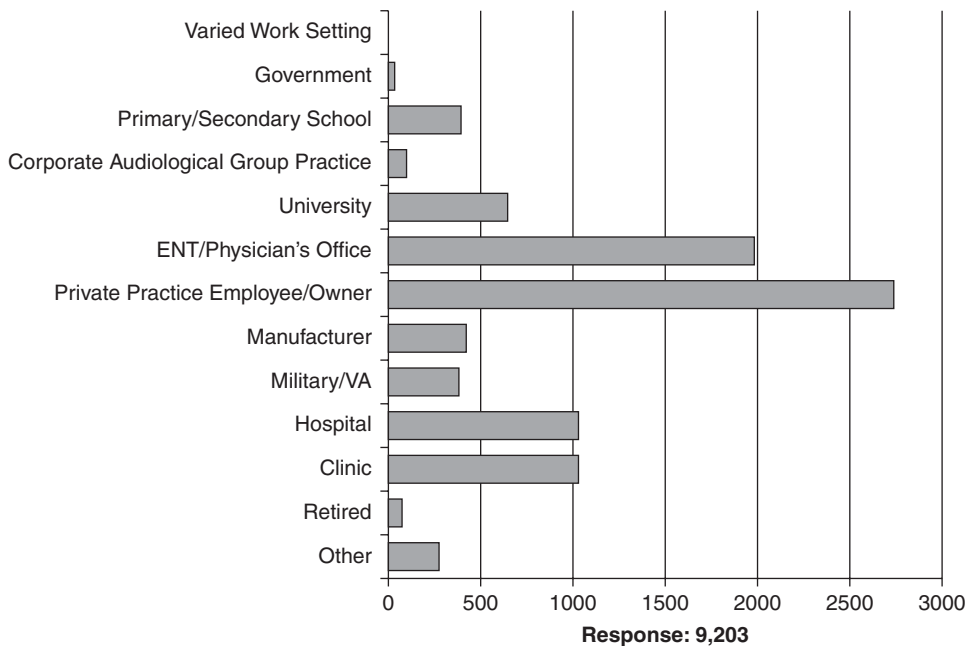


FIGURE 1.4 An American Academy of Audiology membership survey reports that the majority of audiologists are employed within a medical setting (hospital, clinic or physician's office). More than 82 percent of surveyed audiologists report that they are direct providers of clinical services. Contrary to not too many years ago, the single primary employment setting for audiologists is private practice. (Source: American Academy of Audiology, Membership Demographics, 2010.)

Professional Societies

A number of professional societies for the advancement of the interests of audiologists and those they serve has evolved as the profession itself has grown. The American Speech Correction Association (originally founded in 1927 as the American Society for the Study of Disorders of Speech) adopted the new profession of audiology in 1947 when its name was changed to the American Speech and Hearing Association (ASHA). Renamed the American Speech-Language-Hearing Association (www.asha.org) in 1978 (while retaining its recognized acronym), ASHA was instrumental in setting standards for the practice of audiology and for the accreditation of academic programs for audiologists and speech-language pathologists. ASHA provides continuing education and professional and scientific journals for these two professions, which share a common heritage.

Recognizing the necessity for a strong national association that could represent the unique needs and interests of the audiology profession, the American Academy of Audiology (AAA) (www.audiology.org) was founded in 1988. Rapidly embraced by the profession, AAA became the home of more than 6,000 audiologists before it was 10 years old and well over 10,000 by the time the academy was 20 years old. The Academy is committed to the advancement of audiological services through increased public awareness of hearing and balance disorders among the U.S. population as well as national governmental agencies and congressional representatives. The Academy's journals and continuing education programs are instrumental in audiologists maintaining a high level of expertise in their chosen profession. AAA, along with ASHA, continues to set and revise practice standards, protocols, and guidelines for the practice of audiology to ensure quality patient care.

In addition to belonging to one or both of the national associations for audiology as well as their state academy of audiology, many practitioners will belong to organizations that promote

their own particular chosen area of expertise. Audiologists may affiliate with other audiologists with similar interests through the Academy of Rehabilitative Audiology (www.audrehab.org), the Academy of Doctors of Audiology (www.audiologist.org), or the Educational Audiology Association (www.edaud.org). The American Auditory Society (www.amauditorysoc.org) presents a unique opportunity for audiologists to interact with a variety of medical and nonmedical professionals whose endeavors are largely directed toward work with those who have hearing impairment. Finally, some audiologists will find professional growth through affiliation with one or more of the primarily consumer-oriented associations such as the Hearing Loss Association of America (www.hearingloss.org), and the Alexander Graham Bell Association for the Deaf and Hard of Hearing (www.agbell.org).

Summary

Relative to other professions in the health arena, audiology is a newcomer, emerging from the combined efforts of otology and speech pathology during World War II. Following the war, this new area of study and practice grew rapidly within the civilian sector because of the high prevalence of hearing loss in the general population and the devastating effects on individuals and families when hearing loss remains untreated. To fully support the needs of those served, especially within the pediatric population, a close working relationship is often maintained with speech-language pathologists and educators of those with hearing impairment. A mutual respect for what each profession brings to the (re)habilitation of those with hearing impairments leads to the highest level of remediation for those served.

Today the profession of audiology supports a variety of specialty areas and is moving toward a professional doctorate as the entry-level degree. Given projected population demographics, students choosing to enter this profession will find themselves well placed for professional growth and security.

Related Websites

www.betterhearing.org/sound

This website from the Better Hearing Institute gives a comparative audio demonstration of perceived speech through normal hearing ears and ears with mild and moderate hearing loss. A variety of speech samples are presented in varying environments.

The following websites may be accessed to connect to professional and consumer organizations related to audiological concerns, professional issues, legislative initiatives, service providers, and consumer education.

- Academy of Doctors of Audiology, www.audiologist.org
- Academy of Rehabilitative Audiology, www.audrehab.org
- Alexander Graham Bell Association for the Deaf and Hard of Hearing, www.agbell.org
- American Academy of Audiology, www.audiology.org
- American Auditory Society, www.amauditorysoc.org
- American Board of Audiology, www.americanboardofaudiology.org
- American Speech-Language-Hearing Association, www.asha.org
- American Tinnitus Association, www.ata.org
- Council for Accreditation in Occupational Hearing Conservation, www.caohc.org
- Deafness Research Foundation, www.drf.org
- Educational Audiology Association, www.edaud.org
- Facility for the Education and Testing of Canine Hearing/Laboratory for Animal Bioacoustics, <http://homepages.uc.edu/csd/fetchlab>
- Hearing Loss Association of America, www.hlaa.org
- Military Audiology Association, www.militaryaudiology.org

Study Questions

1. Why is it important for speech-language pathologists to have a working knowledge of audiology?
2. List the specialty areas of audiology and the types of employment settings in which they may be practiced.
3. What purpose do professional societies serve for the profession of audiology and its practitioners?
4. Briefly outline the evolution of audiology.
5. Discuss the economic burden hearing loss presents to society.
6. What is the difference between a license to practice one's profession and professional certification?

Suggested Readings

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American Speech-Language-Hearing Association. (2004). Scope of practice in audiology. *Asha*, 24 (Suppl.), 35–37.

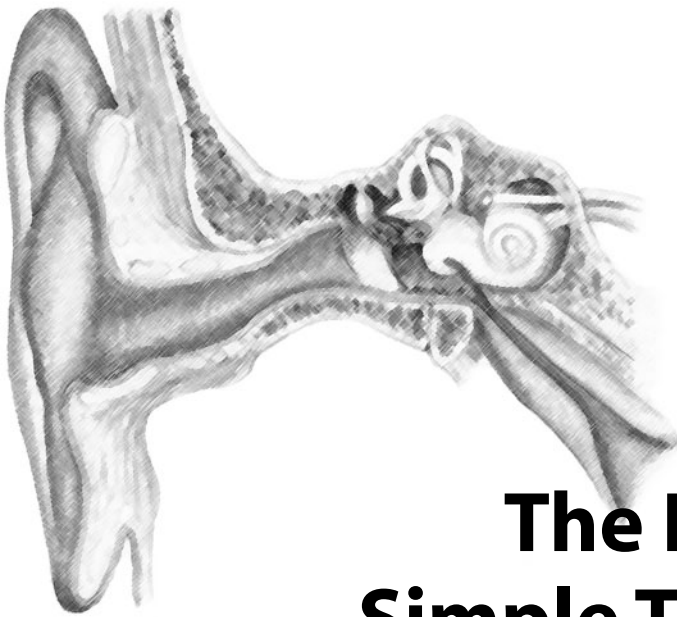
Endnotes

1. Dr. Raymond Carhart (1912–1975), largely regarded as the “Father of Audiology.”

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The Human Ear and Simple Tests of Hearing

ANATOMY IS CONCERNED with how the body is structured, and physiology is concerned with how it functions. To facilitate understanding, the anatomist neatly divides the mechanisms of hearing into separate compartments, at the same time realizing that these units actually function as one. Sound impulses pass through the **auditory** tract, where they are converted from acoustical to mechanical to hydraulic to chemical and electrical energy, until finally they are received by the brain, which makes the signal discernible.

We test human hearing by two sound pathways, **air conduction** and **bone conduction**. Tests of hearing utilizing **tuning forks** are by no means modern, but they illustrate hearing via these two pathways. Tuning-fork tests may compare the hearing of the patient to that of a presumably normal-hearing examiner, the relative sensitivity by air conduction and bone conduction, the effects on bone conduction of closing the opening into the ear, and the lateralization of sound to one ear or the other by bone conduction.

LEARNING OBJECTIVES

The purpose of this chapter is to present a simplified explanation of the mechanism of human hearing and to describe tuning-fork tests that provide information about hearing disorders. Because of the structure of this chapter, some of the statements have been simplified. These basic concepts are expanded in later chapters in this book. Upon completion of this chapter, the reader should be able to

- Define a basic vocabulary relative to the ear.
- Understand the core background for study of more sophisticated hearing tests.

- Describe the general anatomy of the hearing mechanism and its pathways of sound.
- List and describe the three types of hearing loss presented.
- Outline the expected tuning-fork test results for different types of hearing loss.

Anatomy and Physiology of the Ear

A simplified look at a coronal section through the ear (Figure 2.1) illustrates the division of the hearing mechanism into three parts. The **outer ear** comprises a shell-like protrusion from each side of the head, a canal through which sounds travel, and the **eardrum membrane** (more correctly called the tympanic membrane) at the end of the canal. The **middle ear** consists of an air-filled space with a chain of tiny bones, the third of which, the stapes, is the smallest in the human body. The portion of the **inner ear** that is responsible for hearing is called the **cochlea**; it is filled with fluids and many microscopic components, all of which serve to convert waves into a message that travels to the stem (base) of the brain via the **auditory nerve**. The brain stem is not coupled to the highest auditory center in the cortex by a simple neural connection. Rather, there is a series of waystations that receive, analyze, and transmit impulses along the auditory pathway.

1. Name the three main parts of the ear.

2. What is the connection between the inner ear and the brain?



For additional illustrations of the anatomy of the ear, see the section on Anatomy under Learning Supplements on the Companion Website.

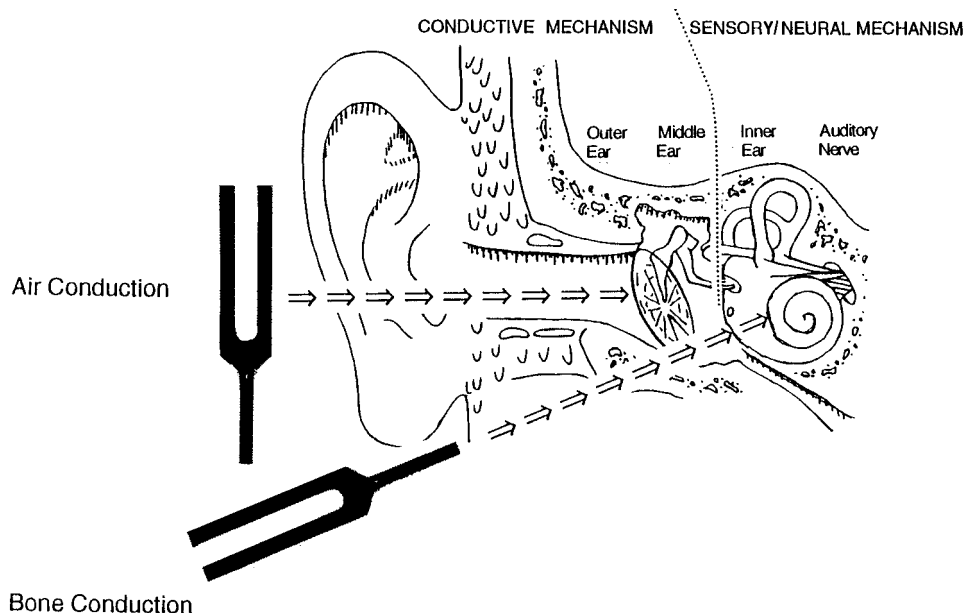


FIGURE 2.1 Cross-section of the ear showing the air-conduction pathway and the bone-conduction pathway. Stimuli reaching the inner ear directly by bone conduction bypass the conductive mechanisms of the outer ear and the middle ear.

1. outer ear, middle ear, inner ear; 2. auditory nerve

Pathways of Sound

Those persons whose primary interest is in the measurement of hearing sometimes divide the hearing mechanism differently than do anatomists. Audiologists and physicians separate the ear into the conductive portion—consisting of the outer and middle ears—and the sensory/neural portion—consisting of the inner ear and the auditory nerve. This type of breakdown is illustrated in the block diagram in Figure 2.2.

Any sound that courses through the outer ear, middle ear, inner ear, and beyond is heard by air conduction. It is possible to bypass the outer and middle ears by vibrating the skull mechanically and stimulating the inner ear directly. In this way the sound is heard by bone

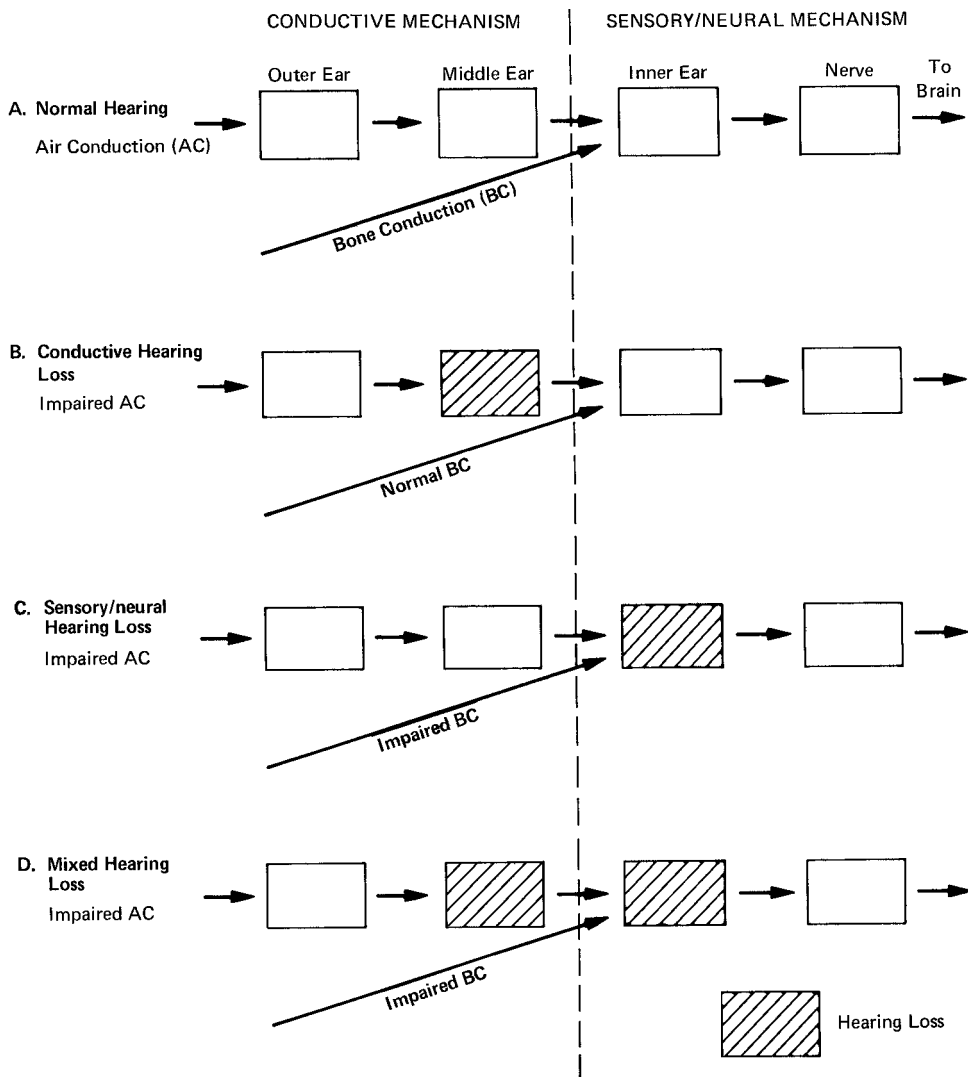


FIGURE 2.2 Block diagram of the ear. A conductive hearing loss is illustrated by damage to the middle ear. Damage to the outer ear would produce the same effect. Similarly, a sensory/neural hearing loss could be illustrated by damage to the hearing nerve as well as to the inner ear.

conduction. Therefore, hearing by air conduction depends on the functioning of the outer, middle, and inner ear and of the neural pathways beyond; hearing by bone conduction depends on the functioning of the inner ear and beyond.

Types of Hearing Loss

Conductive Hearing Loss

A decrease in the strength of a sound is called **attenuation**. Sound attenuation is precisely the result of a conductive hearing loss. Whenever a barrier to sound is present in the outer ear or middle ear, some loss of hearing will result. Individuals will find that their sensitivity to sounds that are introduced by air conduction is impaired by such a blockage. If the sound is introduced by bone conduction, it bypasses the obstacle and goes directly to the sensory/neural mechanism. Because the inner ear and the other sensory/neural structures are unimpaired, the hearing by bone conduction will be normal. This impaired air conduction with normal bone conduction is called a **conductive hearing loss** and is diagrammed in Figure 2.2B. In this illustration the **hearing loss** is caused by damage to the middle ear. Outer ear abnormalities produce the same relationship between air and bone conduction.

Sensory/Neural Hearing Loss

If the disturbance producing the hearing loss is situated in some portion of the sensory/neural mechanism, such as the inner ear or the auditory nerve, a hearing loss by air conduction will result. Because the attenuation of the sound occurs along the bone-conduction pathway, the hearing loss by bone conduction will be as great as the hearing loss by air conduction. When a hearing loss exists in which there is the same amount of attenuation for both air conduction and bone conduction, the conductive mechanism is eliminated as a possible cause of the difficulty. A diagnosis of **sensory/neural hearing loss** can then be made. In Figure 2.2C the inner ear was selected to illustrate a sensory/neural disorder, although the same principle would hold if the auditory nerve were damaged.

For some time hearing loss resulting from damage to the inner ear or to the auditory nerve was called either a “perceptive loss” or a “nerve loss.” Both these terms are inaccurate (although the latter is, regrettably, still used today by some individuals). The term “perceptive loss” is misleading as perception is achieved by centers in the brain and thereby removed from either the inner ear or the auditory nerve. The term “nerve loss” is equally misleading given that the auditory nerve is far less common than the inner ear as the site of these hearing losses.

Several decades ago the term “sensori-neural” was introduced to suggest that the problem involved the inner ear and/or the auditory nerve. This was a considerable advance toward accuracy in scientific terminology, although technically a hyphenated word must contain two accepted words and “sensori” does not appear in the dictionary. The term “sensori-neural” also suffers from the fact that a hyphen implies a connection between two words, but not one and/or the other. Over time the hyphen was dropped and the compound word “sensorineural” was coined, a term that fails to acknowledge that such losses are rarely both sensory and neural. The term adopted for this book uses the slash with a slight spelling change, namely, “sensory/neural,” as this more strongly indicates that the damage may be to the inner ear, to the auditory nerve, or possibly both. Diagnostic audiology is well on its way toward differentiating sensory from neural hearing losses, and when that eventuality is fully realized, the use of hyphens, slashes, or compound words will no longer be necessary.

Mixed Hearing Loss

Problems can occur simultaneously in both the conductive and sensory/neural mechanisms, as illustrated in Figure 2.2D. This results in a loss of hearing sensitivity by bone conduction because of the sensory/neural abnormality, but an even greater loss of sensitivity by air conduction. This is true because the loss of hearing by air conduction must include the loss (by bone conduction) in the sensory/neural portion plus the attenuation in the conductive portion. In other words, sound traveling on the bone-conduction pathway will be attenuated only by the defect in the inner ear, but sound traveling on the air-conduction pathway will be attenuated by both middle-ear and inner-ear problems. This type of impairment is called a **mixed hearing loss**.

3. What are the three main types of hearing loss?

Erroneous Hearing Loss

Individuals are sometimes seen whose test results show some degree of hearing loss, usually sensory/neural, but who either have normal hearing or insufficient auditory pathology to explain the extent of the loss. The mechanisms for this phenomenon are explained more fully in Chapter 13, but the underlying psychodynamics may be quite complex. In the past a simple dichotomy was popular that said that patients with **erroneous hearing loss** were either consciously faking the problem for some financial or other gain, or there was some psychological disorder that manifested in the symptom of a hearing loss. The former condition is called **malinger** and the latter one **psychogenic hearing loss**. Some explanation of this oversimplification will be found later in this book.

Hearing Tests

Some of the earliest tests of hearing probably consisted merely of producing sounds of some kind, such as clapping the hands or making vocal sounds, to see if an individual could hear them. Asking people if they could hear the ticking of a watch or the clicking of two coins together may have suggested that the examiner was attempting to sample the upper pitch range. Obviously, these tests provided little information of either a quantitative or a qualitative nature.

Tuning Fork Tests

The tuning fork (Figure 2.3) is a device, usually made of steel, magnesium, or aluminum, that is used to tune musical instruments or by singers to obtain certain pitches. A tuning fork emits a tone at a particular pitch and has a clear musical quality. When the tuning fork is vibrating properly, the tines move alternately away from and toward one another (Figure 2.4), and the stem moves with a piston action. The air-conduction tone emitted is relatively pure, meaning that it is free of overtones (more on this subject in Chapter 3).

The tuning-fork tests described in this chapter are named for the four German otologists (ear specialists) who described them in the middle 19th to early 20th centuries. They are rarely used by audiologists, who prefer more sophisticated electronic devices. However, tuning-fork tests serve to illustrate the principles involved in certain modern tests.



FIGURE 2.3 Several tuning forks. The larger forks vibrate at lower frequencies (produce lower-pitched tones) than the smaller forks.

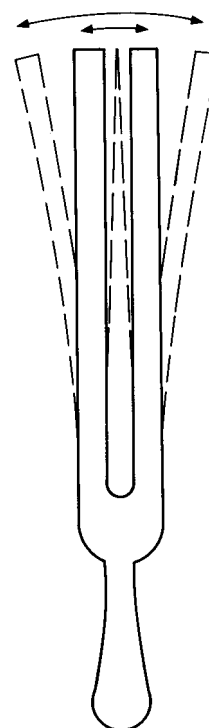


FIGURE 2.4 Vibration pattern of tuning forks.

The tuning fork is set into vibration by holding the stem in the hand and striking one of the tines against a firm but resilient surface. The rubber heel of a shoe does nicely for this purpose, although many physicians prefer the knuckle, knee, or elbow. If the fork is struck against too solid an object, dropped, or otherwise abused, its vibrations may be considerably altered.



To see how a tuning fork is activated, see the video titled “Tuning-Fork Tests” in the Clinical Demonstrations section of the Companion Website.

The tuning fork was adopted as an instrument for testing hearing over a century ago. It held promise then because it could be quantified, at least in terms of the pitch emitted. Several forks are available that usually correspond to notes on the musical scale of C. By using tuning forks with various known properties, hearing sensitivity through several pitch ranges may be sampled. However, any diagnostic statement made on the basis of a tuning-fork test is absolutely limited to the pitch of the fork used because hearing sensitivity is often different for different pitches.

4. Every tuning fork is designed to vibrate at a single _____.

The Schwabach Test

The **Schwabach test**¹, introduced in 1890, is a bone-conduction test. It compares the hearing sensitivity of a patient with that of an examiner. The tuning fork is set into vibration, and the stem is placed alternately against the **mastoid process** (the bony protrusion behind the ear) of the patient and of the examiner (Figure 2.5A). Each time the fork is pressed against the patient's head, the patient indicates whether the tone is heard. The vibratory energy of the tines of the fork decreases over time, making the tone softer. When the patient no longer hears the tone, the examiner immediately places the stem of the tuning fork behind his or her own ear and, using a watch, notes the number of seconds that the tone is audible after the patient stops hearing it.

This test assumes that examiners have normal hearing, and it is less than worthless unless this is true. If both examiners and patients have normal hearing, both will stop hearing the tone emitted by the fork at approximately the same time. This is called a *normal Schwabach*. If patients have sensory/neural hearing loss, hearing by bone conduction is impaired, and they will stop hearing the sound much sooner than the examiner. This is called a *diminished Schwabach*. The test can be quantified to some degree by recording the number of seconds an examiner continues to hear the tone after a patient has stopped hearing it. If an examiner hears the tone for 10 seconds longer than a patient, the patient's hearing is "diminished 10 seconds." If patients have a conductive hearing loss, bone conduction is normal, and they will hear the tone for at least as long as the examiner, and sometimes longer. In some conductive hearing losses, the patient's hearing in the low-pitch range may appear to be better than normal. When this occurs, the result is called a *prolonged Schwabach*.

Difficulties arise in the administration and interpretation of the Schwabach test. Interpretation of test results in cases of mixed hearing losses is especially difficult. Because

5. The Schwabach test is designed to compare _____ to _____.

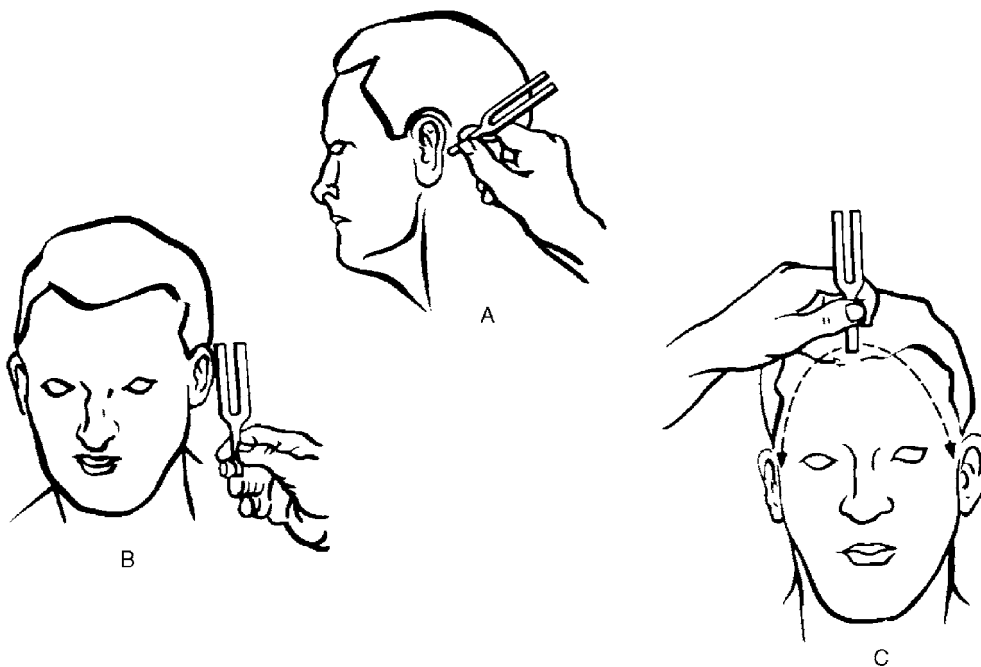


FIGURE 2.5 Positions of tuning fork during tuning-fork tests.

5. the patient's hearing by bone conduction, the examiner's hearing by bone conduction

both inner ears are very close together and are embedded in the bones of the skull, it is virtually impossible to stimulate one without simultaneously stimulating the other. Therefore, if there is a difference in sensitivity between the two inner ears, a patient will probably respond to sound heard through the better ear, which can cause a *false normal Schwabach*. Thus, the examiner may have difficulty determining which ear is actually being tested.



To see a demonstration of the Schwabach test, see the video titled “Tuning-Fork Tests” on the Companion Website.

The Rinne Test

Performance of the **Rinne test**² compares patients’ hearing sensitivity by bone conduction to their sensitivity by air conduction. This is done by asking them to state whether the tone is louder when the tuning-fork stem is held against the bone behind the ear, as in the Schwabach test (Figure 2.5A), or when the tines of the fork that are generating an air-conducted sound are held next to the opening of the ear (Figure 2.5B). Because air conduction is a more efficient means of sound transmission to the inner ear than bone conduction, people with normal hearing will hear a louder tone when the fork is next to the ear than when it is behind the ear. This is called a *positive Rinne*. A positive Rinne also occurs in patients with sensory/neural hearing loss. The attenuation produced by a problem in the sensory/neural mechanism produces the same degree of loss by air conduction as by bone conduction (Figure 2.2C).

If patients have more than a mild conductive hearing loss, their bone-conduction hearing is normal (Figure 2.2B), and they will hear a louder tone with the stem of the fork behind the ear (bone conduction) than with the tines at the ear (air conduction). This is called a *negative Rinne*. Sometimes patients manifest what has been called the *false negative Rinne*, which occurs when the inner ear not deliberately being tested responds to the tone. As mentioned in the discussion of the Schwabach test, this may happen readily during bone-conduction tests. For example, if the right ear is the one being tested, the loudness of the air-conducted tone in the right ear may inadvertently be compared to the loudness of the bone-conducted tone in the left ear. If the left-ear bone conduction is more sensitive than the right-ear bone conduction, a false negative Rinne may result, giving rise to an improper diagnosis of conductive hearing loss.

6. The Rinne test is designed to compare the patient’s hearing by _____ to his/her hearing by _____.



To see a demonstration of the Rinne test, see the video titled “Tuning-Fork Tests” on the Companion Website.

The Bing Test

For some time it has been known that when persons with normal hearing close off the opening into the ear canal, the loudness of a tone presented by bone conduction increases. This phenomenon has been called the **occlusion effect**, and it is observed primarily for low-pitched sounds. This effect is also evident in patients with sensory/neural hearing loss, but it is absent in patients with conductive hearing loss. This is the premise of the **Bing test**.³

When performing the Bing test, the tuning fork handle is held to the mastoid process behind the ear (Figure 2.5A) while the examiner alternately closes and opens the ear canal with a finger. For normal hearers and those with sensory/neural hearing loss, the result is a pulsating sound, or a sound that seems to get louder and softer (called a *positive Bing*). For patients with conductive hearing losses, no change in the loudness of the sound is noticed (*negative Bing*). The examiner must not suggest to patients what their responses should be. As in the Schwabach and Rinne tests, the danger of a response to the tone by the nontest ear is ever present.

7. The Bing test determines the presence of the _____.

The Weber Test

Since its introduction, the **Weber test**⁴ has been so popular that it has been modified by many audiologists for use with modern electronic testing equipment. It is a test of **lateralization**; that is, patients must state where they hear the tone (left ear, right ear, both ears, or midline).

When performing the Weber test, the tuning fork is set into vibration, and the stem is placed on the midline of the patient's skull. Figure 2.5C shows placement on the forehead, which is probably the most popular location. Other sites are also used, such as the top or the back of the head, the chin, or the upper teeth. In most cases the upper teeth produce the loudest bone-conducted sound. Patients are simply asked in which ear they hear a louder sound. Often the reply is that they hear it in only one ear.

People with normal hearing or with equal amounts of the same type of hearing loss in both ears (conductive, sensory/neural, or mixed) will report a midline sensation. They may say that the tone is equally loud in both ears, that they cannot tell any difference, or that they hear the tone as if it originated somewhere in the middle of the head. Patients with sensory/neural hearing loss in one ear will hear the tone in their better ear. Patients with conductive hearing loss in one ear will hear the tone in their poorer ear.

The midline sensation is easy to understand. If the ears are equally sensitive and equally stimulated, equal loudness should logically result. One explanation of the Weber effect in sensory/neural cases is based on the Stenger effect. The **Stenger principle** states that if two tones that are identical in all ways except loudness are introduced simultaneously into both ears, only the louder tone will be perceived. When the bone-conduction sensitivity is poorer in one ear than in the other, the tone being introduced to both ears with equal energy will be perceived as softer or will not be perceived at all in the poorer ear.

Results on the Weber test are most poorly understood in unilateral conductive hearing losses. The explanation for the tone being louder in the ear with a conductive loss than in the normal ear is probably based on the same phenomenon as prolonged bone conduction, described briefly in the discussion of the Schwabach test.

The Weber test has been known to avert misdiagnosis of unilateral sensory/neural hearing loss as conductive when false normal Schwabach or false negative Rinne results are seen, but the tone is heard in the poorer-hearing ear rather than the expected better-hearing ear. The Weber test is quick, easy, and often helpful, although like most auditory tests, it has some drawbacks. Clinical experience has shown that many patients with a conductive hearing loss in one ear report hearing the tone in their better ear because what they are actually experiencing seems incorrect or even foolish to them. Again, care must be taken not to lead patients into giving the kind of response they think is "correct." Interpretation of the Weber test is also difficult in mixed hearing losses.

8. The Weber test is one of _____.

Clinical Commentary

Electronic tests for testing hearing by bone conduction have largely supplanted tuning-fork tests in audiological testing; however, tuning-fork tests continue to be used by many otologists. The Bing and Weber tests can be easily performed with today's electronic test equipment and can prove useful in separating conductive from sensory/neural hearing loss if other testing proves somewhat ambiguous.

EVOLVING CASE STUDIES

As you read the following case histories, try to see why they have been placed in their different diagnostic categories. For each of the cases, predict what the results would be on the Rinne, Schwabach, and Weber tuning-fork tests when these are possible. Make your predictions before you read the Test Results and Conclusions. In later chapters you will be asked to conjecture about a variety of other, more sophisticated test procedures for these four cases. Diagnostic and treatment information about these cases will unfold in Chapters 4, 5, 7, 8, 10, 11, 13, 14, and 15.

Case Study 1: Conductive Hearing Loss

This is a 23-year-old woman with a history of ear infections since early childhood. She says that while she is always aware of a hearing loss, it appears to vary in degree. She says she can understand speech well if people are close to her or speak loudly. The otologist who referred her for testing says that while there is evidence of past infection, her tympanic membranes are both intact.

Case Study 2: Sensory/Neural Hearing Loss

This 76-year-old male denies any history of ear infection or exposure to loud noise. He first noticed some difficulty in hearing about 15 years earlier and says that it has progressed and that he does much better in quiet surroundings than in noisy places or where there are several people speaking at the same time. His difficulty in correctly identifying words is more bothersome than the loss of the loudness of speech, and he does not like people shouting at him. His wife volunteers that in recent years the patient has significantly reduced his interactions with others and avoids movies, the theater, and religious services because he has so much trouble understanding words.

Case Study 3: Erroneous Hearing Loss

This patient, a 45-year-old male who works in a factory, has recently brought a legal suit against his employer because of a claimed hearing loss. He states that one day at work there was a very loud explosion about 10 yards to his left and that since that time he can hear nothing in his left ear but has no trouble hearing in his right ear. When you stand several feet away on his right side he is able to answer all your questions. When you stand the same distance on his left side he says he cannot hear you at all. He speaks adamantly about his belief that his work setting is responsible for his difficulty and also claims to have very loud ringing in his left ear.

Case Study 4: Pediatric Patient

Interview with the parents indicates that your patient is a 3-year-old-female who uses no spoken language. The parents have sought a diagnosis of her delayed language from a variety of specialists including her pediatrician and a psychologist. Several tentative diagnoses have been made including mental retardation and autism. Her older brother was speaking in complete sentences when he was much younger than this little girl. The parents are desperate for a diagnosis so they can begin to try to help their child. Recently the patient was seen by a speech-language pathologist who suggested the possibility of hearing loss as an etiological factor and referred her to you. The child has no history of ear infections. She is thought to respond inconsistently to sound, although her mother has always believed that some hearing loss exists. Although this child passed a neonatal hearing screening before she was released from the hospital, the possibility, however small, of a false negative test result must be borne in mind given the history.

Tuning-Fork Test Results and Conclusions**Case Study 1**

The patient shows a negative Rinne in both ears, a normal Schwabach, and the tone does not lateralize on the Weber test, but rather is heard equally loudly in both ears.

These findings, along with the case history, are consistent with a conductive hearing loss in both ears.

Case Study 2

This patient shows a positive Rinne and a prolonged (lengthened) Schwabach in both ears. The Weber is unlateralized. The case history, especially the difficulty in speech understanding, even when the signal is sufficiently loud, are all consistent with a sensory/neural hearing loss, which is borne out by the tuning-fork test results. Given the age of onset of the hearing loss, it can be reasonably supposed that his hearing loss was produced by aging.

Case Study 3

Results show a positive Rinne for the right ear, and the patient claims that the tone in the left ear is not heard by either air conduction or bone conduction. The Schwabach is normal on the right side, and the patient claims that he does not hear the bone-conducted tone at all on the left side. The Weber is lateralized to the right ear.

Suspicion of a feigned or exaggerated (erroneous) hearing loss is first raised by the legal action, with promise of financial gain, and by the fact that a noise loud enough to cause a hearing loss in his left ear would probably have caused some hearing loss in his right ear as well. It is also true that he should have heard speech in his right ear that was directed to his left side. This is because the shadow of sound (the amount of energy lost as a signal travels from one side of the head to the other) is only about 13 dB. If he truly had a sensory/neural hearing loss in his left ear, he would have been able to hear the bone-conducted signals on the Rinne and the Schwabach in his right ear, since practically no sound intensity is lost as the signal travels through the skull from one side of the head to the other.

Case Study 4

While otolaryngologists frequently perform tuning-fork tests, audiologists rarely do. Regardless, tuning-fork tests for small children are inappropriate and would not be indicated in this case. Your casual observation of the child suggests that she does not appear to respond to environmental sounds. Your first session consisted of observation and the introduction of earphones without an insistence to place them over the child’s ears. Sound-field audiometry and visually reinforced audiometry were briefly attempted, but were unsuccessful as the child tired quickly. The little girl was allowed to play with some toys and was observed to relax. After taking a complete history, the parents were encouraged to observe the child’s reactions to environmental sounds, follow up with the speech-language pathologist, and return in several days for further audiometric testing. The parents appeared relieved and made a new appointment. If hearing loss is confirmed on further testing, a referral will be needed to an otolaryngologist as a first step in attempts to determine the cause of hearing loss.

Summary

The mechanisms of hearing may be roughly broken down into conductive and sensory/neural portions. Tests by air conduction measure sensitivity through the entire hearing pathway. Tests by bone conduction sample the sensitivity of the structures from the inner ear and beyond, up to the brain. The Schwabach test compares the bone-conduction sensitivity of the patient to that of a presumed normal-hearing person (the examiner); the Rinne tuning-fork test compares patients’ own hearing by bone conduction to their hearing by air conduction in order to sample for conductive versus sensory/neural loss; the Bing test samples for conductive hearing loss by testing the effect of occluding the ear; and the Weber test checks for lateralization of a bone-conducted tone presented to the midline of the skull to determine if a loss in only one ear is conductive or sensory/neural.

Related Website

www.webster.edu/~davittdc/ear/rinne/rinne.htm

This website describes and provides a detailed description and instructive video of the Rinne tuning-fork

test, one of the more common of the tuning-fork tests. Additional tuning fork illustration is provided on the text’s accompanying Companion Website.

REVIEW TABLE 2.1 Types of Hearing Loss

<i>Anatomical Area</i>	<i>Purpose</i>	<i>Type of Loss</i>
Outer Ear	Conduct sound energy	Conductive
Middle Ear	Conduct sound energy Increase sound intensity	Conductive
Inner Ear	Convert mechanical to hydraulic to electrochemical energy	Sensory/neural
Auditory Nerve	Transmit electrochemical (nerve) impulses to brain	Sensory/neural

REVIEW TABLE 2.2 Tuning Fork Tests

<i>Test</i>	<i>Purpose</i>	<i>Fork Placement</i>	<i>Normal Hearing</i>	<i>Conductive Loss</i>	<i>Sensory/neural Loss</i>
Schwabach	Compare patients BC to normal	Mastoid process	<i>Normal Schwabach</i> - Patient hears tone as long as examiner	<i>Normal or Prolonged Schwabach</i> - Patient hears tone as long as or longer than examiner	<i>Diminished Schwabach</i> - Patient hears tone for shorter time than examiner
Rinne	Compare patient's AC to BC	Alternately mastoid process and opening to ear canal	<i>Positive Rinne</i> - Louder at the ear	<i>Negative Rinne</i> - Louder behind the ear	<i>Positive Rinne</i> - Louder at the ear
Bing	Determine presence or absence of occlusion effect	Mastoid process	<i>Positive Bing</i> - Tone is louder with ear occluded	<i>Negative Bing</i> - Loudness does not change with ear occluded	<i>Positive Bing</i> - Tone is louder with ear occluded
Weber	Check lateralization of tone in unilateral losses	Midline of head	Tone equally loud in both ears	Tone louder in poorer ear	Tone louder in better ear

REVIEW TABLE 2.3 Relationship Between Air Conduction and Bone Conduction for Different Hearing Conditions

<i>Finding</i>	<i>Condition</i>
Normal air conduction	Normal hearing
Normal bone conduction	Normal hearing of conductive hearing loss
Poorer hearing for air conduction than for bone conduction	Conductive or mixed hearing loss
Hearing for air conduction the same as hearing for bone conduction	Normal hearing or sensory/neural hearing loss

Study Questions

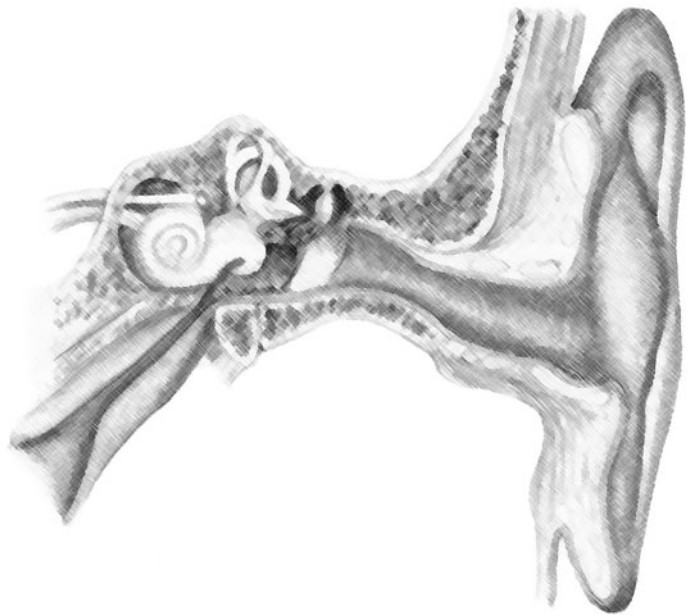
- Sketch a diagram of the ear. Mark the conductive and sensory/neural areas.
- What information is derived from bone conduction that cannot be inferred from air conduction?
- Why is it a good idea to use more than one tuning-fork when doing tuning-fork tests?
- Why are statements regarding the results of different tuning-fork tests limited to the pitch of the fork used?
- What are the probable results on the four tuning-fork tests described in this chapter for a person with a conductive hearing loss in the right ear? State results for both ears.
- What is implied if a person's hearing sensitivity is reduced by air conduction but is normal by bone conduction?
- What is implied if a person's hearing sensitivity is reduced by air conduction and is reduced the same amount by bone conduction?
- What are some of the problems with tuning-fork tests?
- What is the Stenger principle?

Endnotes

- Named for Dr. Dabobert Schwabach (1846–1920).
- Named for Dr. Heinrich Rinne (1819–1868).
- Named for Dr. Albert Bing (1844–1922).
- Named for Dr. Friedrich Weber (1832–1891).

CHAPTER 3

Sound and Its Measurement



IT IS IMPOSSIBLE to study abnormalities of human hearing without a basic understanding of the physics of sound and some of the properties of its measurement and perception. Sound is generated by vibrations and is carried through the air around us in the form of pressure waves. It is only when a sound pressure wave reaches the ear that hearing may take place.

Many factors may affect sound waves during their creation and propagation through the air, and most are specified physically in terms of the frequency and intensity of vibrations. Human reactions to sound are psychological and reflect such subjective experiences as pitch, loudness, sound **quality**, and the ability to tell the direction of a sound source.

LEARNING OBJECTIVES

Understanding this chapter requires no special knowledge of mathematics or physics, although a background in either or both of these disciplines is surely helpful. From this chapter, readers should be able to

- Describe sound waves and their common attributes and express the way these characteristics are measured.
- Discuss the basic interrelationships among the measurements of sound and be able to do some simple calculations (although at this point it is more important to grasp the physical concepts of sound than to gain skill in working equations).
- Have an understanding of the different references for the decibel and when they are used.
- State the difference between physical acoustics and psychoacoustics.
- Discuss the reasons for audiometer calibration and in general terms what this may entail.

Sound

Sound may be defined in terms of either psychological or physical phenomena. In the psychological sense, a sound is an auditory experience—the act of hearing something. In the physical sense, sound is a series of disturbances of molecules within, and propagated through, an elastic medium such as air.

Sound may travel through any elastic medium, although our immediate concern is the propagation of sound through air. Every cubic inch of the air that surrounds us is filled with billions and billions of tiny molecules. These particles move about randomly, constantly bouncing off one another. The **elasticity**, or springiness, of any medium is increased as the distance between the molecules is decreased. If a springy object is distorted, it will return to its original shape. The rate at which this occurs is determined by the elasticity of the object. Molecules are packed more closely together in a solid than in a liquid and more closely in a liquid than in a gas. Therefore, a solid is more elastic than a liquid, and a liquid is more elastic than a gas.

When water is heated in a kettle, the molecules begin to bounce around, which in turn causes them to move farther apart from one another. The energy increases until steam is created, resulting in the familiar teakettle whistle as the molecules are forced through a small opening. As long as there is any heat in the air, there is particle vibration. The rapid and random movement of air particles is called **Brownian motion**¹ and is affected by the heat in the environment. As the heat is increased, the particle velocity is increased.

Waves

Whenever air molecules are disturbed by a body that is set into **vibration**, they move from the point of disturbance, striking and bouncing off adjacent molecules. Because of their elasticity, the original molecules bounce back after having forced their neighbors from their previous positions. When the molecules are pushed close together, they are said to be condensed or compressed. When a space exists between areas of compression, this area is said to be rarefied.

The succession of molecules being shoved together and then pulled apart sets up a motion called **waves**. Waves through the air, therefore, are made up of successive **compressions** and **rarefactions**. Figure 3.1A illustrates such wave motion and shows the different degrees of particle density. Figure 3.1B illustrates the same wave motion as a function of time.

1. Sound travels through air in the form of _____.

Transverse Waves

The molecular motion in **transverse waves** is perpendicular to the direction of wave motion. The example of water is often useful in understanding transverse wave motion. If a pebble is dropped into a water tank, a hole is made in the area of water through which the pebble falls (Figure 3.2A). Water from the surrounding area flows into the hole to fill it, leaving a circular trough around the original hole (Figure 3.2B). Water from the area surrounding the trough then flows in to fill the first trough (Figure 3.2C). As the circles widen, each trough becomes shallower, until the troughs are barely perceptible. As the water flows in to fill the hole, the waves move out in larger and larger circles. In water, then, a float would illustrate a fixed point on the surface, which could be seen to bob only up and down. In fact, the movement of the float would describe a circle or ellipse on a vertical axis, while the waves moving outwardly would describe movement on the horizontal axis. This horizontal movement creates what are called transverse waves.

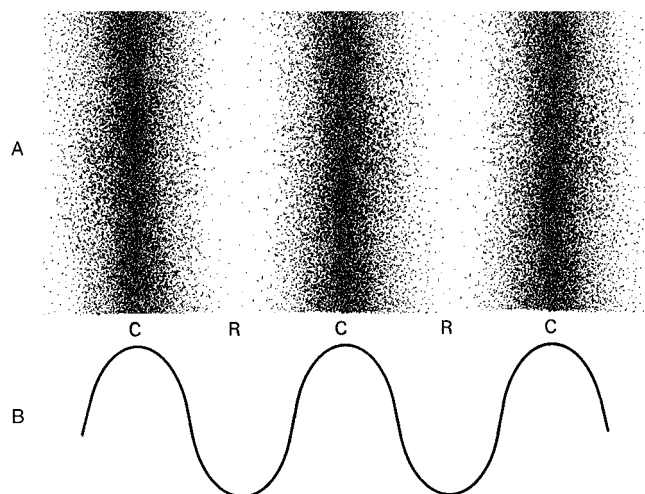


FIGURE 3.1 Simple wave motion in air showing (A) particle displacement (movement of pressure waves through space) and (B) sinusoidal waveform (the pressure wave displayed as a function of time). Note the compressions (C) and rarefactions (R).

Longitudinal Waves

Another kind of wave, more important to the understanding of sound, is the **longitudinal wave**. This wave is illustrated by the motion of wheat blowing in a field, with the tips of the stalks representing the air particles. The air molecules, like the grains of wheat, move along the same axis as the wave itself when a force, such as that provided by the wind, is applied.

Sine Waves

Sound waves pass through the air without being seen. Indeed, they are real, even if there is no one there to hear them. It is useful to depict sound waves in a graphic way to help explain them. Figure 3.3 assists with such a pictorial representation if the reader will concede a bird's-eye view of a bucket of paint suspended by a string above a sheet of paper. If the bucket

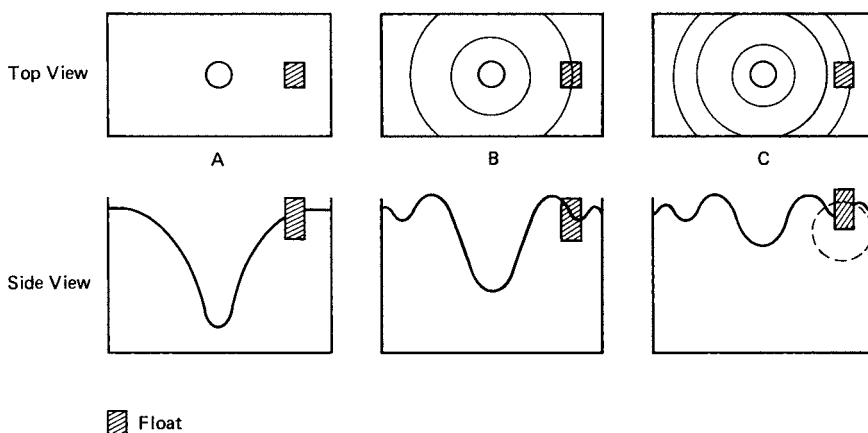


FIGURE 3.2 Wave motion in water as an example of transverse waves. A hole in the water is produced by a pebble (A); the first trough is produced when water flows in to fill the hole (B); the second trough is produced when water flows in to fill the first trough (C). A cork on the surface bobs up and down in a circular fashion.

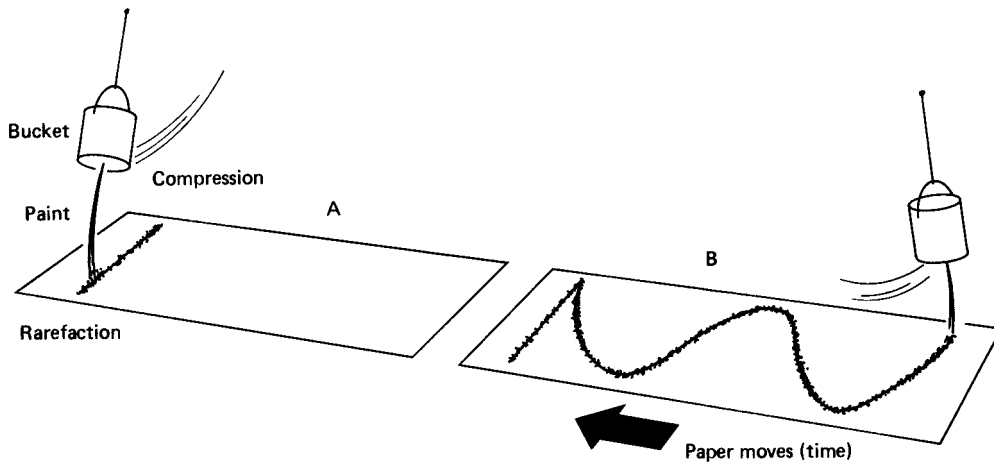


FIGURE 3.3 Sinusoidal motion. Bird's-eye view of a stream of paint from a bucket tracing a line forward (compression) and backward (rarefaction) on a sheet of paper (A). When the paper is moved to the left to represent the passage of time (B), the paint traces a sinusoidal wave.

is pushed forward and backward, a small hole in its bottom allows a thin stream of paint to trace a line on the paper. We assume that forward motions of the bucket stand for compressions of molecules and backward motions for rarefactions. If the bucket continues to swing at the same rate, and if the paper is moved in a leftward direction to represent the passage of time, a smooth wave is painted on the paper; this represents each **cycle**, consisting of its compression and rarefaction, as a function of time. If the movement of the paper takes one second, during which two complete cycles take place, the **frequency** is two cycles per second (cps) and so forth.

A body moving back and forth is said to oscillate. One cycle of vibration, or **oscillation**, begins at any point on the wave and ends at the identical point on the next wave. This definition of an oscillation allows for a number of mathematical analyses that are important in the study of acoustics. Such waves are called **sine waves** or **sinusoidal** (sine-like) waves. When a body oscillates sinusoidally, showing only one frequency of vibration with no tones superimposed, it is said to be a **pure tone**. The number of complete sine waves that occur in one second constitutes the frequency of that wave. The compression of a sine wave is usually shown by the extension of the curve upward, and rarefaction by the extension of the curve downward. One cycle may be broken down into 360 degrees (Figure 3.4). Looking at a sine wave in terms of degrees is useful, as is seen later in this chapter. When a wave begins at 90 degrees rather than at 0 degrees, it is called a **cosine wave**.

2. Three types of waves discussed in this book are _____, _____, and _____.

3. Waves are described as a series of _____ and _____.

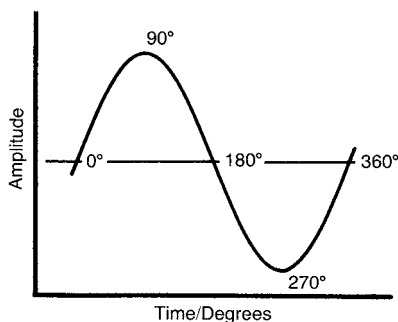
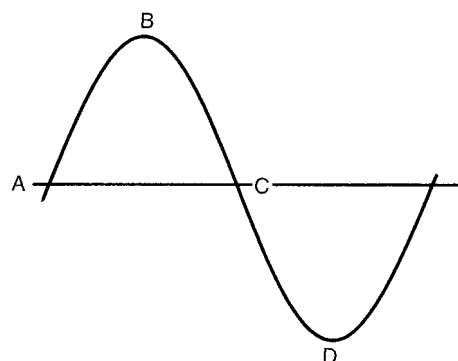


FIGURE 3.4 Denotation of a sine wave into 360 degrees.

FIGURE 3.5 The effects of energy on a vibrating object. The object is at rest at point A. At point B maximum excursion from the resting position has occurred, and all motion stops prior to the return swing. At point B all energy is potential with zero kinetic energy. At point C maximum velocity is reached, so all energy is kinetic and none is potential. Swinging slows down as point D is approached (the same as at point B), and when point D is reached all energy is potential again.



Vibrations

Given the proper amount of energy, a mass can be set into vibration. The properties of its vibration may be influenced by a number of factors.

Effects of Energy on Vibration

Figure 3.5 illustrates the effects of energy on a sine wave. When the oscillating body has swung from point A to point B, it must come to a stop before the onset of the return swing, as the paint bucket in Figure 3.3 must cease its forward swing before it can swing back. At this point there is no **kinetic** (moving) **energy**, but rather all the energy is **potential**. As the vibrating body picks up speed going from B to D, it passes through point C, where there is maximum kinetic energy and no potential energy. As point D is approached, kinetic energy decreases and potential energy increases, as at point B.

Free Vibrations

An object that is allowed to vibrate—for example, a weight suspended at the end of a string (Figure 3.6A)—will encounter a certain amount of opposition to its movement by the molecules in the air. This small amount of friction converts some of the energy involved in the initial

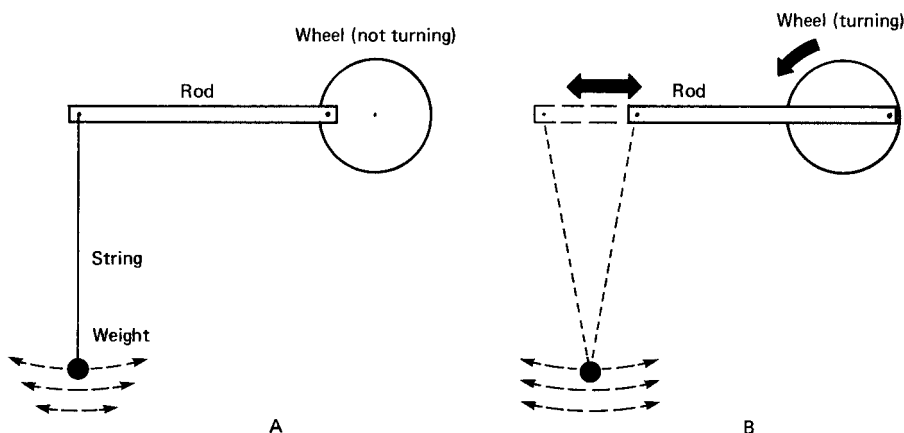


FIGURE 3.6 Free and forced vibrations. If the weight at the end of the string in A is pushed, the swinging back and forth will decrease until it stops. If the rod is caused to move back and forth because of the motion of the wheel (B), the distance of the swing of the weight will remain uniform until the wheel ceases to turn. A illustrates free vibration; B, forced vibration.

movement of the object into heat. Friction has the effect of slowing down the distance of the swing until eventually all swinging will stop. If no outside force is added to perpetuate the swinging, the movement is called a **free vibration**. When the vibrations of a mass decay gradually over time, the system is said to be lightly damped. Heavy **damping** causes the oscillations to cease rapidly. When the oscillations cease before a single cycle is completed, the system is said to be critically damped.

Forced Vibrations

If an outside force is added to a swinging motion that controls the vibration (Figure 3.6B), swinging will continue unaltered until the outside force is removed. Such movement is called a **forced vibration**. When the external force is removed, the object simply reverts to a condition of free vibration, decreasing the distance of its swing until it becomes motionless. In both free and forced vibrations, the number of times the weight moves back and forth (the frequency) is unaltered by the distance of the swing (the amplitude). As the amplitude of particle movement decreases, the velocity of movement also decreases.

Frequency

Nothing may transpire without the passage of time, and it may be questioned how often, or how frequently, an event occurs during some period of time. Occurrences may be rated by using such units as the day or minute; in acoustics, however, when referring to events per unit of time, the duration usually used is the second. Consider the familiar metronome, whose pendulum swings back and forth. Any time the pendulum has moved from any still position to the far right, then past the original position to the far left, and then back to the point of origin, one cycle has occurred. Other motions, such as from far left to far right and back again, would also constitute one cycle. If the time required to complete a cycle is one second, it could be said that the frequency is 1 cycle per second (cps). For some time the term **hertz (Hz)**,² instead of cps, has been adopted as the unit of frequency. The metronome may be adjusted so that the swings of the pendulum occur twice as often. In this way each journey of the pendulum must be made in half the time. This would mean that the time required for each cycle (the **period**) is cut to one-half second. Consequently, the frequency is doubled to 2 Hz. This reciprocal relationship between frequency and period always exists and may be expressed as

$$\text{Period} = 1/\text{frequency}$$

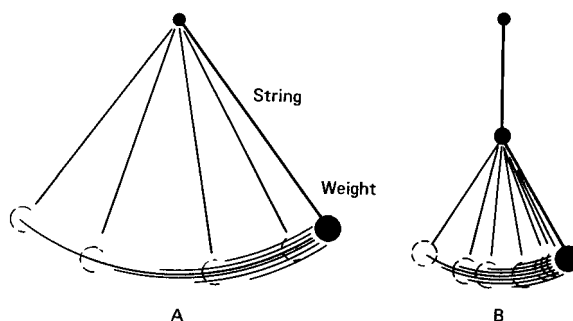
Effects of Length on Frequency

With a little imagination, the swinging of an object suspended at the end of a string can be seen to move slowly back and forth (Figure 3.7A). If the length of the string were suddenly shortened by holding it closer to the weight (Figure 3.7B), the number of swings per second would increase, causing the weight to swing back and forth more frequently. Thus, as length decreases, frequency increases. Conversely, as length increases, the number of hertz decreases. The musical harp exemplifies the effects of length on frequency; as the strings get shorter, they are easily seen (and heard) to vibrate at a higher frequency.

For a demonstration of frequency, see the video entitled “Sound Waveforms” in the Clinical Demonstrations section on the Companion Website.



FIGURE 3.7 Effects of the length of a pendulum on the frequency of the vibration. Given a length of string, the weight at the end will swing back and forth a specific number of times per second. If the string is shortened (B), the weight will swing faster (increase in frequency).



Effects of Mass on Frequency

A greater **mass** of an oscillating system results in a decrease in velocity to keep the kinetic energy constant. Simply stated, as the mass is increased, the frequency of vibration is decreased. For example, consider that the increased thickness of the larger strings of a harp produces lower notes.

Effects of Stiffness on Frequency

4. The two major effects on frequency are _____ and _____.

As a body vibrates, it exhibits a certain amount of compliance (the reciprocal of **stiffness**). As the compliance increases, the frequency at which the body is most easily made to vibrate (the resonant frequency) decreases. Systems that have more elasticity vibrate better at higher frequencies than at lower frequencies.

Resonance

Almost any mass, regardless of size, may be set into vibration. Because of its inherent properties, each mass has a frequency at which it vibrates most naturally—that is, the frequency at which it is most easily set into vibration and at which the magnitude of vibration is greatest and decays most slowly. The natural rate of vibration of a mass is called its **resonant frequency**. Although a mass may be set into vibration by a frequency other than its resonant frequency, when the external force is removed, the oscillation will revert to the resonant frequency until it is damped.

Musical notes have been said to shatter a drinking glass. This is accomplished when the resonant frequency of the glass is produced, and the **amplitude** of the sound (the pressure wave) is increased until the glass is set into vibration that is sympathetic to (the same as) the sound source. If the glass is made to vibrate with sufficient amplitude, its shape becomes so distorted that it shatters.

Sound Velocity

The **velocity** of a sound wave is the speed with which it travels from the source to another point. Sound velocity is determined by a number of factors, one of the most important of which is the density of the medium. As stated earlier, molecules are packed closer together in a solid than in a liquid or gas, and more closely in some solids (or liquids or gases) than in others. The closer together the

molecules, the shorter the journey each particle makes before striking its neighbor, and the more quickly the adjacent molecules can be set into motion. Therefore, sounds travel faster through a solid than through a liquid and faster through a liquid than through a gas. In audiology, our concern is with the movement of sound through air. The velocity of sound in air is approximately 344 meters (1,130 feet) per second at standard temperature-pressure conditions (20° Celsius at sea level). When temperature and humidity are increased, the speed of sound increases. At higher altitudes the speed of sound is reduced because the distance between molecules is greater.

The velocity of sound may be determined at a specific moment; this is called the instantaneous velocity. In many cases, sound velocity fluctuates as the wave moves through a medium. In such cases, the average velocity of the wave may be determined by dividing the distance traveled by the time interval required for passage. Although we often think of velocity in miles per hour (mph), we can shift our thinking to meters per second (m/s) or centimeters per second (cm/s). When velocity is increased, acceleration takes place. When velocity is decreased, deceleration occurs.

As a solid object moves through air, it pushes the air molecules it strikes out of the way, setting up a wave motion. If the object itself exceeds the speed of sound, it causes a great compression ahead of itself, leaving a partial vacuum behind. The compressed molecules rushing in to fill the vacuum result in a sudden overpressure, called the sonic boom. An aircraft flying faster than the speed of sound is first seen to pass by; followed by the boom; followed by the sound of the aircraft approaching, flying overhead, and departing. The loud sound of a gun discharging is made not so much by the explosion of gunpowder as by the breaking of the sound barrier (exceeding the speed of sound) as the bullet leaves the barrel.

5. The velocity of sound is its _____.

Wavelength

A characteristic of sound proportionately related to frequency is **wavelength**. The length of a wave is measured from any point on a sinusoid (any degree from 0 to 360) to the same point on the next cycle of the wave (Figure 3.8). The formula for determining wavelength is $w = v/f$, where w = wavelength, v = the velocity of sound, and f = frequency. To solve for velocity, the formula $v = fw$ is used; to solve for frequency, $f = v/w$ is used. As frequency goes up, wavelength decreases. For example, the wavelength of a 250 Hz tone is 4.5 feet ($w = 1130/250$), whereas the wavelength of

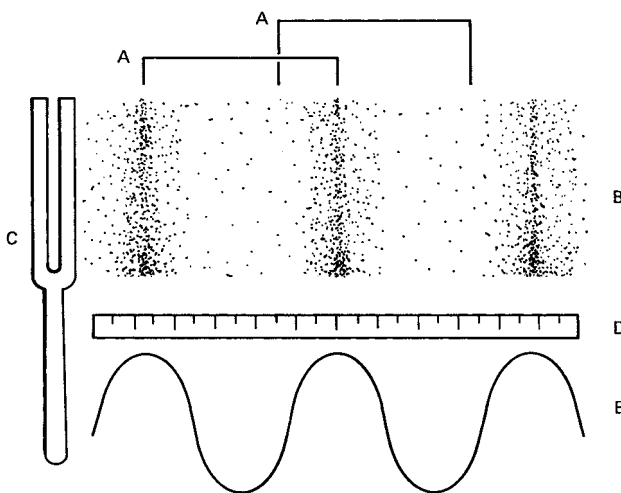


FIGURE 3.8 Wavelength (A) is measured from any point on the pressure wave to the same point (in degrees) on the next wave. Pressure waves (B) are set up in the air by the vibrating tines of the tuning fork (C). These waves move a given distance as measured by the meter stick (D) and also may be displayed as a function of time (E).

6. The formula for wavelength is _____.

an 8000 Hz tone is 0.14 feet ($w = 1130/8000$). Expressed in the metric system, the wavelength for a 250 Hz tone is 1.4 meters ($w = 344/250$) and for an 8000 Hz tone, 0.04 meters ($w = 344/8000$).

Clinical Commentary

A common complaint among those with hearing loss is difficulty hearing someone speaking from another room. The reason for this difficulty is more easily understood when one is familiar with the wavelength of sounds. The longer wavelengths of the lower-frequency sounds of vowels more easily move around corners and obstructions than do the shorter wavelengths of the higher frequencies contained in many of the consonants of speech.



For a demonstration of the effects of frequency on wavelength see the video entitled “Sound Waveforms” in the Clinical Demonstrations section on the Companion Website.

Phase

It is convenient to discuss the relationships among corresponding points on different waves in terms of the angular measurements used to describe circular motion. Any point on a sine wave (expressed in degrees) may be compared to a standard. This standard is considered to be zero degrees. If an oscillation has a beginning at 0 (or 360) degrees, it is said to be in **phase** with the standard (Figure 3.9A). Tones presented out of phase (Figure 3.9B, C, and D) are discussed in terms of differences in degrees from the standard function of time.

Interference

Whenever more than one tone is introduced, there are interactions among sound waves. Such interactions are determined by the frequency, intensity, and phase relationships of the different waves. At any given moment the instantaneous amplitudes of concurrent sound waves are summed. Two tones of the same frequency and phase relationship will reinforce each other, increasing the amplitude. Two tones of identical frequency, but 180 degrees out of phase, will cancel each other, resulting in 0 amplitude at any given moment. Away from laboratory conditions, there are usually more than two concomitant signals, so complete **cancellation** and complete reinforcement rarely occur.

Beats

When two tones of almost identical frequency are presented (e.g., 1000 and 1003 Hz), there will be a noticeable increase and decrease in the resulting sound intensity, which is determined by the separation of the tones in frequency (in this illustration, 3 Hz). These changes in amplitude are perceived as **beats**. When one hears two tones of different frequencies, and the difference between the two frequencies is increased, the number of beats per second increases, changing to a pulsing, then to a roughness, and finally to a series of complex sounds. Depending on the starting frequency, when the difference in frequency between two tones becomes large enough, the ear recognizes a number of tones, including the higher one, the lower one, the **difference tone**, and the summation tone, all of which may be expressed in hertz as multiples of the original two tones.

7. The number of beats per second is determined by the difference between two _____.

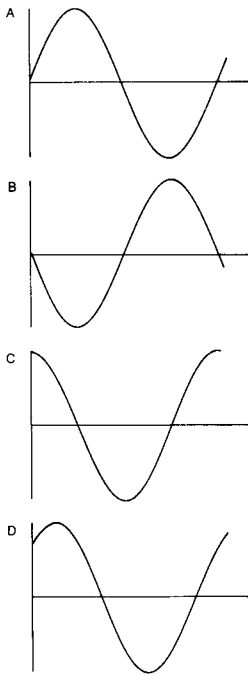


FIGURE 3.9 Relationship of phase on four waves of identical frequency.

Complex Sounds

Pure tones, as described in this chapter, seldom appear in nature. When they are created, it is usually by devices such as tuning forks or electronic sine-wave generators. Most sounds, therefore, are characterized as containing energy at a number of different frequencies, amplitudes, and phase relationships. Fourier³ first showed that any **complex wave** can be analyzed in terms of its sinusoidal **components**.

Fundamental Frequency

When a number of pure tones are presented, one of them will naturally have a frequency lower than the others. The lowest rate of a sound's vibration is called the **fundamental frequency**, which is determined by the physical properties of the vibrating body. Some complex sounds repeat over time, as do many of the sounds of speech and music. Such sounds are called **periodic**. **Aperiodic** sounds vary randomly over time, do not have fundamental frequencies, and are usually perceived as noise.

8. The lowest frequency of vibration in a complex sound is called the _____.

Harmonics

In a periodic complex sound, all frequencies are whole-number multiples of the fundamental. These tones, which occur over the fundamental, are called **harmonics** or **overtones**. The **spectrum** of a sound with a 100 Hz fundamental would therefore contain only higher frequencies of 200 Hz, 300 Hz, 400 Hz, and so on. With respect to periodic signals, the only difference between overtones and harmonics is the way in which they are numbered: The first harmonic is the fundamental frequency, the second harmonic is twice the fundamental, and so on. The first overtone is equal to the second harmonic, and further overtones are numbered consecutively.

Spectrum of a Complex Sound

When two or more pure tones of different frequencies are generated simultaneously, their combined amplitudes must be summed at each instant in time. This is illustrated in Figure 3.10, which shows that a new and slightly different waveform appears. Adding a fourth and fifth tone would further alter the waveform. Complex waves of this nature can be synthesized in the laboratory and constitute, in essence, the opposite of a **Fourier analysis**.

Although the fundamental frequency determines all the harmonic frequencies, the harmonics do not all have equal amplitude (Figure 3.11A). In any wind instrument the fundamental frequency is determined by a vibrating body: in a clarinet, the reed; in a trombone, the lips

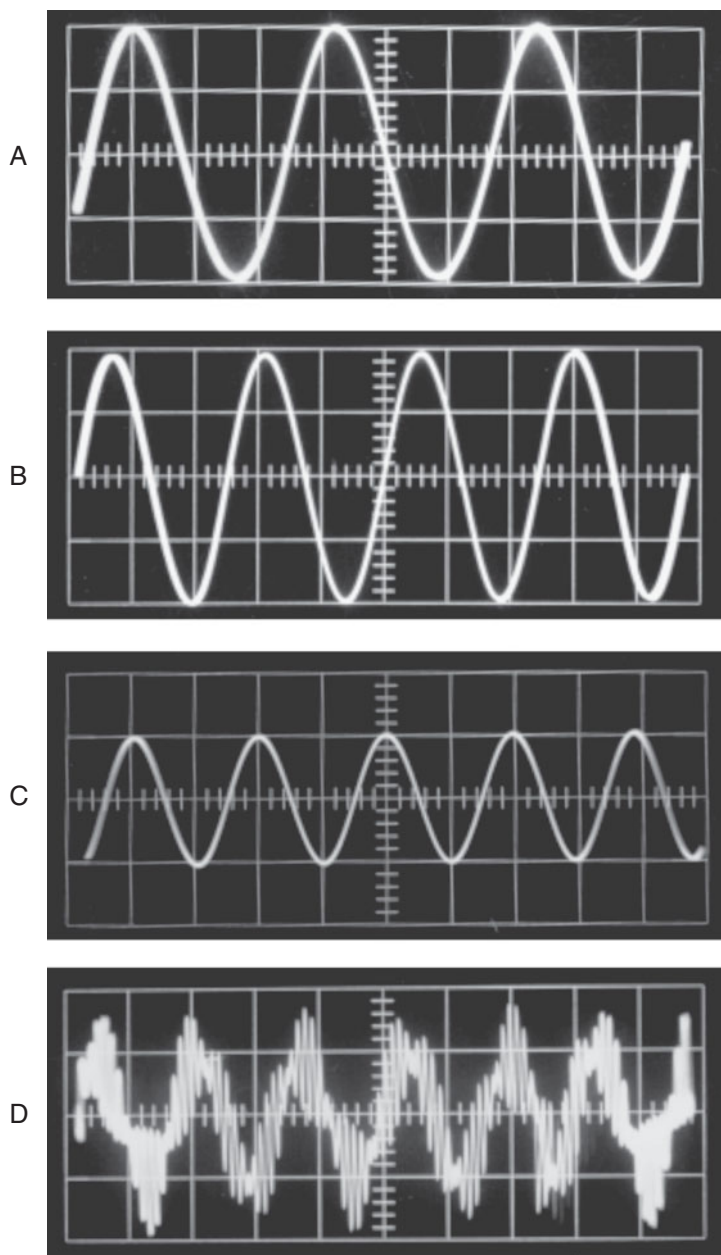


FIGURE 3.10 Synthesis of a complex waveform (D) from three sine waves (A, B, C) of different frequency and/or amplitude. Note that the amplitudes are summed at each moment in time, resulting in a new waveform.

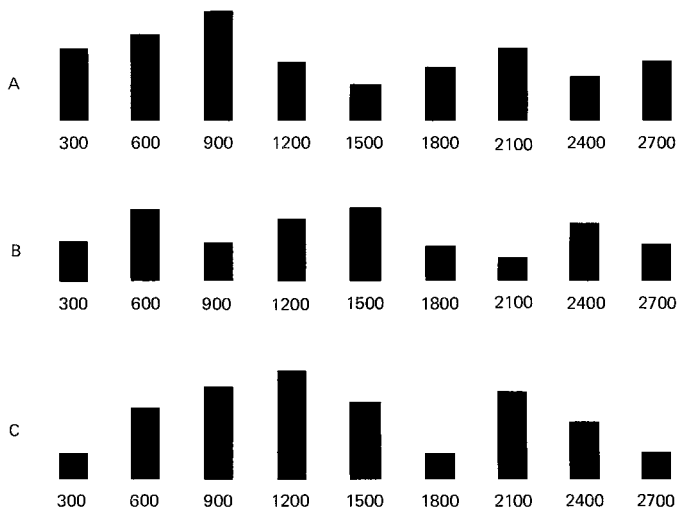


FIGURE 3.11 Histograms showing the spectra of three wind instruments. The fundamental frequency is the same in each (300 Hz), but the amplitudes of the harmonics differ.

within the mouthpiece; and in that peculiar wind instrument called the human vocal tract, the vocal folds in the larynx. The length and cross-sectional areas of any of these wind instruments may be varied: in the trombone, by moving the slide; in the clarinet, by depressing keys; and in the vocal tract, by raising or lowering the tongue and moving it forward or back. In this way, even though the fundamental and harmonic frequencies may be the same, the amplitudes of different harmonics vary from instrument to instrument, resulting in the different harmonic spectrum (Figure 3.11B and C) and characteristic qualities of each.

During speech, altering the size and shape of the vocal tract, mostly by moving the tongue, results in frequency and intensity changes that emphasize some harmonics and suppress others. The resulting waveform has a series of peaks and valleys. Each of the peaks is called a **formant**, and it is manipulation of formant frequencies that facilitates the recognition of different vowel sounds. The peaks are numbered consecutively and are expressed as the lowest, or first, formant (F1), the second formant (F2), and so on. The spectrum of a musical wind instrument may be similar to that of a vowel and is also determined by the resonances of the acoustic systems.

Once the harmonic structure of a wave has been determined by the fundamental, the fundamental is no longer critical for the clear perception of a sound for persons with normal hearing. This is exemplified by the telephone, which does not allow frequencies below about 300 Hz to pass through. Although a man's fundamental vocal frequency averages about 85 to 150 Hz and a woman's about 175 to 250 Hz (both the consequences of laryngeal size, shape, and subglottal pressure), the sex of the speakers, as well as their identities, is evident over a telephone even though the fundamental frequency is filtered out.

9. Formant frequencies of the human voice are determined by the

Intensity

Up to this point we have concerned ourselves with the frequency of vibration and its related functions. It is important that we know not only how fast but also how far a body vibrates—its **intensity**. Figure 3.12A shows two tones of identical frequency; however, there is a difference in the maximum excursions of the two waves. Obviously, a greater **force** has been applied to the

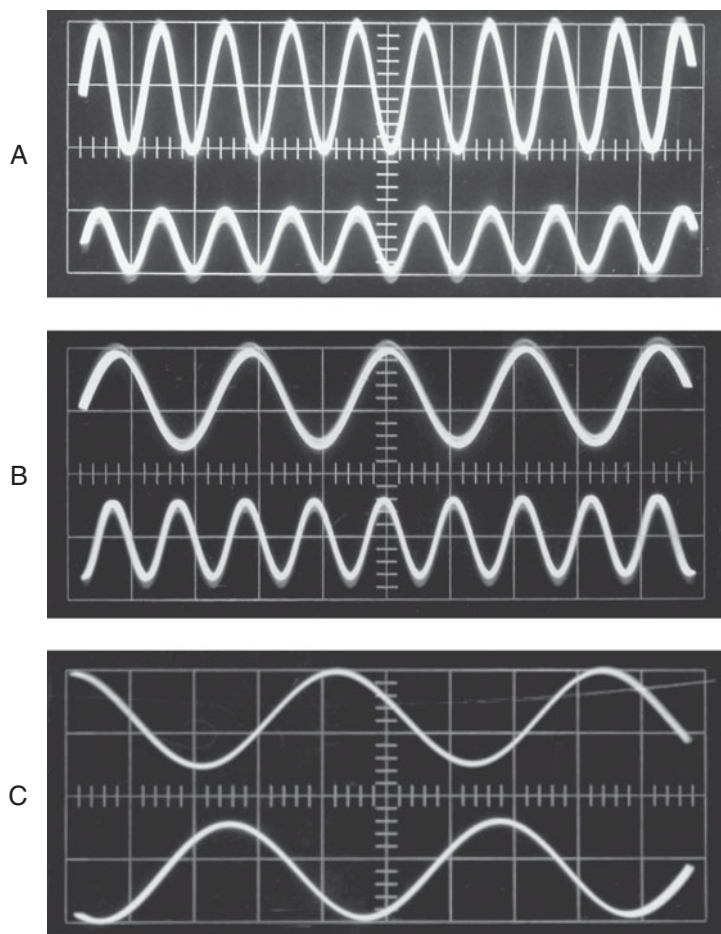


FIGURE 3.12 (A) Two tones of different amplitude (frequency and phase constant), (B) two tones of different frequency (amplitude and phase constant), and (C) two tones differing in phase (amplitude and frequency constant).

wave on the top than to the wave on the bottom to cause this difference to occur. The distance the mass moves from the point of rest is called its amplitude. Because our concern is with particle motion in air, it is assumed that if a greater force is applied to air molecules, they will move further from their points of rest, causing greater compressions and greater rarefactions, increasing the particle displacement and therefore the amplitude. Figure 3.12B shows two tones of identical amplitude and starting phase but of different frequency. Figure 3.12C shows two tones with the same amplitude and frequency but different phase.

10. Two sine waves may be contrasted by their differences in _____, _____, and _____.

Force

When vibrating bodies, such as the tines of a tuning fork, move to and fro, they exert a certain amount of force on adjacent air molecules. The greater the force, the greater the displacement of the tines, and therefore the greater the amplitude of the sound wave. Because of the human ear's extreme sensitivity to sound, only very small amounts of force are required to stimulate hearing. The **dyne (d)** is a convenient unit of measurement for quantifying small changes in force.

One dyne is a force sufficient to accelerate a mass of 1 gram at 1 centimeter per second squared. If a mass of 1 gram (1/30 ounce) is held at sea level, the force of gravity on this mass is about 1000 dynes. The **Newton (N)**⁴ has been used more recently as a force measurement in the United States. One Newton is a force that will accelerate a 1 kg mass at 1 m/s².

Pressure

Pressure is generated whenever force is distributed over a surface area. An example is the number of pounds per square inch used in tire-pressure measurements. Normal atmospheric pressure is 14.7 lb/in², 1 million dynes/cm², or 105 **Pascals (Pa)**.⁵ If a given area remains constant, the pressure increases as the force is increased.

A word might be said here regarding units of measurement. The metric centimeter-gram-second (CGS) system has been popular among scientists in the United States for many years, but is being replaced by the meter-kilogram-second (MKS) system. What might eventually be used exclusively is the International System of Units, abbreviated SI, taken from the French *Le Système International d'Unités*. In the CGS system, pressure is expressed in dynes/cm² and in the SI system as Pascals.

Because of the sensitivity of human hearing, micropascals—millionths of a Pascal (μPa)—are used to express sound pressure in the audible range of intensities for humans and most animals. The smallest pressure variation required to produce a just-audible sound to healthy young ears is approximately 0.0002 dyne/cm², or 20 μPa. Sound waves that may be damaging to the ear have a pressure of about 2×10^8 μPa.

Work

When any mass, such as a group of air particles, is moved, a certain amount of **work** is done as energy is expended. The amount of work done may be expressed as the force exerted times the distance the mass is moved. One **erg (e)** is the amount of work done when a 1 dyne force displaces an object by 1 cm; one **joule (J)**⁶ is 10 million ergs.

Power

Power is the capacity to exert physical force or energy and is expressed as the rate at which energy is expended. Familiar units of power are horsepower and watts.⁷ Because human hearing is extremely sensitive, small units of power, such as the erg per second, are used in acoustics. One watt is equal to 1 million ergs/second or 10^{21} joule per second, and 1 horsepower is equal to 746 watts. Power is a common measure of the magnitude of a sound. As the distance from the source is increased, the sound energy that reaches a given point decreases because the sound's power is spread out over a larger area.

Intensity of a Sound Wave

In any vibration, more air particles are displaced as the distance from the source increases. However, when the intensity of sound is measured, interest is usually centered on a small area at the point of measurement. The intensity of a sound wave is the amount of force per unit of area. It decreases proportionately to the square of the distance from the sound source (the **inverse square law**), so an intensity of 10^{-12} watt/m² (or 10^{-16} watt/cm²) at 1000 Hz will produce a just-audible sound if that intensity reaches the ear.

Assuming that sound radiates in a spherical pattern from a source, this relationship can be expressed by the following formula:

$$\text{Intensity (watts/cm}^2 \text{ or watts/m}^2\text{)} = \frac{\text{power (watts)}}{4\pi \times \text{radius}^2 \text{ (cm or m)}}$$

Common units of measurement, such as the pound or the mile, are additive in nature. As an example, ten 1-pound weights equal exactly 10 pounds. However, because the range of human hearing is so great, using such units results in very large, cumbersome numbers. It is convenient to discuss one intensity in terms of the number of times it is multiplied by another intensity—that is, in terms of a ratio between the two. The **decibel (dB)** is commonly used for this purpose.

 The Decibel

A convenient way of expressing a ratio between two lengthy numbers is to use the **logarithm**. One unit established in such a way is the **Bel**, named for Alexander Graham Bell.⁸ Because a Bel may have a rather large value, the decibel, which is one-tenth of a Bel, is the unit of measurement of intensity used in acoustics and in audiometrics.

11. Decibels cannot be simply added or subtracted because they are _____.

Five important aspects of the decibel must be remembered: (1) It involves a ratio; (2) it utilizes a logarithm; (3) it is therefore nonlinear; (4) it may be expressed in terms of various reference levels, which must be specified; (5) it is a relative unit of measure.

Logarithms

A logarithm (log) is simply a number expressed as an **exponent** (or power) that tells how often a number (the base) is multiplied by itself. In the expression 10² (ten squared), the log (2) tells us that the base (10) will be multiplied by itself one time (10 × 10 = 100). The exponent is the power, which tells us how many times the base will be used in multiplication (e.g., 10³ = 10 × 10 × 10 = 1000).

Although any base may be used, in acoustics the base 10 is most common. This is convenient because the log simply tells how many zeros appear after the 1. Table 3.1 (A and B) shows a natural progression of logarithms with the base 10. It is important to note that the log of 1 is zero.

The logarithm is useful in expressing a **ratio** between two numbers. Remember that a ratio is shown when any number is divided by another number. If a number is divided by itself (e.g., 25 ÷ 25), the ratio is always one to one (1:1), a fact that obtains regardless of the magnitude of the numbers. When numbers with identical bases are used in division, the log of the denominator is subtracted from the log of the numerator (e.g., 10³ ÷ 10² = 10¹). These mathematics do not change, regardless of whether the numerator or the denominator is the larger (e.g., 10² ÷ 10³ = 10⁻¹). When a ratio is expressed as a fraction, the denominator becomes the reference to which the numerator is compared. Ratios expressed without a specific reference are totally meaningless, as in those commercial ads that claim a product is twice as good, three times as bright, or 100% faster, and so on, without saying what it is better, brighter, or faster than.

TABLE 3.1 Ratios, Logarithms, and Outputs for Determining Number of Decibels with Intensity and Pressure References

C Intensity Outputs (I_O)					G Pressure Outputs (P_O)			
A Ratio	B Log	CGS (watt/cm ²)	SI (watt/m ²)	D dB IL*	E Equal Amplitudes	F dB SPL†	CGS (dyne/cm ²)	SI (μ Pa)
Threshold of Audibility								
1:1	0	10 ⁻¹⁶	10 ⁻¹²	0		0	.0002	20.0(2 × 10 ¹)
10:1	1	10 ⁻¹⁵	10 ⁻¹¹	10		20	.002	200.0(2 × 10 ²)
100:1	2	10 ⁻¹⁴	10 ⁻¹⁰	20		40	.02	2,000.0(2 × 10 ³)
1,000:1	3	10 ⁻¹³	10 ⁻⁹	30		60	.2	20,000.0(2 × 10 ⁴)
10,000:1	4	10 ⁻¹²	10 ⁻⁸	40		80	2.0	200,000.0(2 × 10 ⁵)
100,000:1	5	10 ⁻¹¹	10 ⁻⁷	50		100	20.0	2,000,000.0(2 × 10 ⁶)
1,000,000:1	6	10 ⁻¹⁰	10 ⁻⁶	60		120	200.0	20,000,000.0(2 × 10 ⁷)
10,000,000:1	7	10 ⁻⁹	10 ⁻⁵	70		140	2000.0	200,000,000.0(2 × 10 ⁸)
100,000,000:1	8	10 ⁻⁸	10 ⁻⁴	80				
1,000,000,000:1	9	10 ⁻⁷	10 ⁻³	90				
10,000,000,000:1	10	10 ⁻⁶	10 ⁻²	100				
100,000,000,000:1	11	10 ⁻⁵	10 ⁻¹	110				
1,000,000,000,000:1	12	10 ⁻⁴	10 ⁰	120				
10,000,000,000,000:1	13	10 ⁻³	10 ¹	130				
100,000,000,000,000:1	14	10 ⁻²	10 ²	140				
Threshold of Pain								

*The number of dB with an intensity reference ($I_R = 10^{-12} \text{ watt}/\text{m}^2$) uses the formula: $\text{dB (IL)} = 10 \times \log (I_O/I_R)$.

†The number of dB with a pressure reference ($P^k = 20 \mu\text{Pa}$) uses the formula: $\text{dB (SPL)} = 20 \times \log (P_O/P_R)$.

Intensity Level

Under some circumstances, it is useful to express the decibel with an intensity reference. A practical unit in such cases is the watt per meter squared (watt/m^2). The intensity reference in a given system may be expressed as I_R (the number of **watts** of the reference intensity). The output (e.g., a loudspeaker) of the system may be expressed as I_O , so that a ratio may be set up between the intensity reference and the intensity output. In solving for the number of decibels using an intensity reference, the formula is

$$\text{dB} = 10 \times \log (I_O/I_R)$$

The usual intensity reference (I_R) is $10^{-12} \text{ watt/m}^2$ (or sometimes $10^{-16} \text{ watt/cm}^2$), although this may be changed if desired. The exponent tells the number of places the decimal points must be moved to the right or left of the number 1. If the exponent is positive (or unsigned), the number of zeros is added following the 1. If the exponent is negative, the number of zeros placed before the 1 is equal to the exponent minus 1, with a decimal point before the zeros. If the exponent is positive, it suggests a large number; if it is negative, it suggests a small number, less than 1. Therefore, $10^{-12} \text{ watt/m}^2$ is an extremely small quantity ($0.000000000001 \text{ watt/m}^2$).

If the intensity reference of a sound system (I_R) is known, the preceding equation may be used to determine the number of decibels of the output above (or below) the reference. As mentioned earlier, it is essential that the reference always be stated. When the reference is $10^{-12} \text{ watt/m}^2$, the term **intensity level (IL)** may be used as shorthand to imply this reference.

If the intensity output and the intensity reference are exactly the same ($I_O = I_R$), the ratio is 1:1. Because the log of 1 is 0, use of the formula shows the number of decibels to be 0. Therefore, 0 dB does not mean that sound is absent, but rather that the intensity output is the same as the intensity reference. If I_O were changed to 10^1 watt/m^2 , the number of decibels (IL) would be 130. Table 3.1 shows that as the intensity output (C) increases, the ratio (A) increases, raising the power of the log (B) and increasing the number of decibels (D).

It must be remembered that the decibel is a logarithmic expression. When the intensity of a wave is doubled—for example, by adding a second loudspeaker with a sound of identical intensity to the first—the number of decibels is not doubled but is increased by three. This occurs because the intensity outputs of the two signals, and not the number of decibels, are added algebraically according to the principles of wave interference and the rules for working with logs. For example, if loudspeaker A creates a sound of 60 dB IL (10^{-6} watt/m^2) and loudspeaker B also creates a sound of 60 dB IL (10^{-6} watt/m^2) to the same point in space, the result is 63 dB IL ($2 \times 10^{-6} \text{ watt/m}^2$).

Sound-Pressure Level

Audiologists and acousticians are more accustomed to making measurements of sound in pressure than in intensity terms. Such measurements are usually expressed as **sound-pressure level (SPL)**. Because intensity is known to be proportional to the square of pressure, the conversion from intensity to pressure may be made as follows:

$$\text{Intensity reference: dB(IL)} = 10 \times \log (I_O/I_R)$$

$$\text{Pressure reference: dB(SPL)} = 10 \times \log (P_O^2/P_R^2)$$

Because intensity is proportional to pressure squared, to determine the number of decibels from a pressure reference, I_R may be written as P_R^2 (pressure reference) and I_O may be written as

P_O^2 (pressure output). It is a mathematical rule that when a number is squared, its log is multiplied by 2; therefore, the formula for dB SPL may be written

$$\text{dB (SPL)} = 10 \times \log (P_O^2/P_R^2)$$

or

$$\text{dB (SPL)} = 10 \times 2 \times \log (P_O/P_R)$$

or

$$\text{dB (SPL)} = 20 \times \log (P_O/P_R)$$

As in the case of decibels with an intensity reference, when P_O is the same as P_R , the ratio between the two is 1:1 and the number of decibels (SPL) is zero. Just as in the case of intensity, 0 dB SPL does not mean silence; it means only that the output pressure is 0 dB above the reference pressure.

One dyne/cm² is equal to 1 **microbar** (one-millionth of normal barometric pressure at sea level), so the two terms are frequently used interchangeably. The pressure of 0.0002 dyne/cm² has been the sound-pressure reference in physics and acoustics for some time. It is, however, being replaced by its SI equivalent, 20 micropascals (μPa). This is the reference used for most **sound-level meters** (Figure 3.13), devices designed to measure the sound-pressure levels in various acoustical environments. Therefore, 20 μPa is 0 dB SPL. The threshold of pain at the ear is reached at 140 dB SPL. The term dB SPL implies a pressure reference of 20 μPa. Table 3.1 shows



FIGURE 3.13 A commercial sound-level meter designed to measure the sound-pressure levels in various acoustical environments. (Courtesy of Larson-Davis Laboratory, a Division of PCB Piezotronics, Inc.)

that increases in the number of μPa (or dyne/cm^2) (G) is reflected in the ratio (A), the log (B), and the number of dB SPL (F).

Because the decibel expresses a ratio between two sound intensities or two sound pressures, decibel values cannot be simply added and subtracted. Therefore, 60 dB plus 60 dB does not equal 120 dB. When sound-pressure values are doubled, the number of decibels is increased by six. Therefore, 60 dB (20,000 μPa) plus 60 dB (20,000 μPa) equals 66 dB (40,000 μPa). In actual fact, the SPL will increase by a factor of 3 dB unless the two waves are in perfect correspondence. Also, because of the special relationship between intensity and sound pressure, a 6 dB increase will be shown if the number of loudspeakers is quadrupled, unless they are all in phase.

Note that the amplitude of a wave, whether expressed in decibels with an intensity reference or a pressure reference (Table 3.1, columns C and G), is the same as long as the number of decibels is the same. Intensity and pressure are simply different ways of looking at the same wave. Column E of Table 3.1 is designed to illustrate this point.

Hearing Level

The modern audiometer was designed as an instrument to test hearing sensitivity at a number of different frequencies. Originally, each audiometer manufacturer determined the SPL required to barely stimulate the hearing of an average normal-hearing individual. Needless to say, there were

some differences from manufacturer to manufacturer. Studies were then conducted (e.g., Beasley, 1938) in which the hearing of many young adults was carefully measured. The resulting data culminated in the standard adopted in 1951 by the American Standards Association (ASA). This organization has been renamed the **American National Standards Institute (ANSI)**.

The lowest sound intensity that stimulates normal hearing is called zero **hearing level (HL)**. Because the ear shows different amounts of sensitivity to different frequencies (being most sensitive in the 1000 to 4000 Hz range), different amounts of pressure are required for 0 dB HL at different frequencies. Even early audiometers were calibrated so that hearing could be tested over a wide range of intensities, up to 110 dB HL (above normal hearing thresholds) at some frequencies. The pressure reference for decibels on an audiometer calibrated to ASA-1951 specifications was therefore different at each frequency, but the hearing-level dial was calibrated with reference to normal hearing (audiometric zero).

An international organization covering 148 countries (with one member per country) was created to establish a wide variety of standards in various practices. This organization is called the International Organization for Standardization and has a Central Secretariat in Geneva, Switzerland, where the organization is based. It was recognized that a single international abbreviation was needed for the organization to be recognized around the world, but due to differences in languages this presented a problem. For example, the abbreviation would be “IOS” in English, “OIN” in French (for Organisation Internationale de Normalisation), etc. The decision was to use a word derived from the Greek *isos*, meaning, “equal.” Therefore, the organization’s name is ISO in all countries regardless of language.

Audiometers manufactured in different countries had slightly different SPL values for audiometric zero until a standard close to what had been used in Great Britain was adopted by the **International Organization for Standardization (ISO)**. This revised standard, which was called ISO-1964, showed normal hearing to be more sensitive than the 1951 ASA values, resulting in a lowering of the SPL values averaging approximately 10 dB across frequencies. Differences between the two standards probably occurred because of differences in the studies during which normative data were compiled, in terms of test environment, equipment, and procedure.

12. The decibel reference
on audiometers is

TABLE 3.2 Reference Equivalent Threshold Sound Pressure Levels (RETSPLs) (dB re 20 μ Pa) for Supra-Aural Earphones (ANSI, 2004)

Frequency Hz	Supra-Aural Earphone		
	TDH Type ^a JE318C IEC318	TDH 39 NBS9A	TDH 49/50 BS9A
125	45.0	45.0	47.5
160	38.5		
200	32.5		
250	27.0	25.5	26.5
315	22.0		
400	17.0		
500	13.5	11.5	13.5
630	10.5		
750	9.0	8.0	8.5
800	8.5		
1000	7.5	7.0	7.5
1250	7.5		
1500	7.5	6.5	7.5
1600	8.0		
2000	9.0	9.0	11.0
2500	10.5		
3000	11.5	10.0	9.5
3150	11.5		
4000	12.0	9.5	10.5
5000	11.0		
6000	16.0	15.5	13.5
6300	21.0		
8000	15.5	13.0	13.0
Speech	20.0	19.5	20.0

Audiologists who had experience testing normal-hearing persons on the ASA standard had noted that many such subjects had hearing better than the zero reference, often in the -10 dB HL range, and welcomed the conversion to the ISO standard. More recently, a new American standard has been published by the American National Standards Institute (ANSI, 2004) showing SPL values for normal hearing using supra-aural audiometer earphones close to the ISO levels (see Table 3.2). These values are termed the *reference equivalent threshold sound-pressure levels* (RETSPLs).

Sensation Level

Another reference for the decibel may be the auditory **threshold** of a given individual. The threshold of a pure tone is usually defined as the level at which the tone is so soft that it can be perceived only 50% of the time it is presented; however, the 50% response criterion is purely arbitrary. The number of decibels of a sound above the threshold of a given individual is the sound's **sensation level** (SL) in decibels.

If a person can barely hear a tone at 5 dB HL at a given frequency, a tone presented at 50 dB HL will be 45 dB above his or her threshold, or, stated another way, 45 dB SL. The same 50 dB HL tone presented to a person with a 20 dB threshold will have a sensation level of

13. Any discussion of decibels must include their ____.

30 dB. It is important to recognize that a tone presented at threshold has a sensation level of 0 dB. To state the number of dB SL, the threshold of the individual (the reference) must be known.

 Environmental Sounds

Earlier we saw that the range of sound intensities, from threshold of audibility to pain in the ear, is extremely wide. All of the sounds that normal-hearing persons may hear without discomfort must be found within this range. Table 3.3 gives examples of some ordinary environmental sounds and their approximate intensities. This table may help the reader to develop a framework from which to approximate the intensities of other sounds.

 Psychoacoustics

Thus far in this chapter, attention has been focused on physical acoustics. These factors are the same with or without human perception. It is also important that consideration be allocated to psychoacoustics, the study of the relationship between physical stimuli and the psychological responses to which they give rise.

Pitch

Pitch is a term used to describe the subjective impressions of the “highness” or “lowness” of a sound. Pitch relates to frequency; in general, pitch rises as the frequency of vibration increases, at least within the range of human hearing (20 to 20,000 Hz). The Western world uses the **octave** scale in its music. When frequency is doubled, it is raised one octave, but raising (or lowering) a sound one octave does not double (or halve) its pitch. Intensity also contributes to the perception of pitch, although to a lesser extent than does frequency.

TABLE 3.3 Scale of Intensities for Ordinary Environmental Sounds*

<i>Decibels*</i>	<i>Sound</i>
0	Just audible sound
10	Soft rustle of leaves
20	A whisper at 4 feet
30	A quiet street in the evening with no traffic
40	Night noises in the city
50	A quiet automobile 10 feet away
60	Department store
70	Busy traffic
60–70	Normal conversation at 3 feet
80	Heavy traffic
80–90	Niagara Falls
90	A pneumatic drill 10 feet away
100	A rivet gun 35 feet away
110	Hi-fidelity phonograph with a 10-watt amplifier, 10 feet away
115	Hammering on a steel plate 2 feet away

*The reference is 10^{−16} watt/cm² (Van Bergeijk, Pierce, & David, 1960).

For a demonstration of the effects of frequency on pitch perception, see the video entitled “Sound Waveforms” in the Clinical Demonstrations section on the Companion Website.



The subjective aspect of pitch can be measured by using a unit called the **mel**. One thousand mels is the pitch of a 1000 Hz tone at 40 dB SL. Frequencies can be adjusted so that they sound twice as high (2000 mels), half as high (500 mels), and so on. Except for the fact that the number of mels increases and decreases with frequency, apart from 1000 Hz, the numbers do not correspond. Although the task sounds formidable, pitch scaling can be accomplished on cooperative, normal-hearing subjects with great accuracy after a period of training. The mel scale is illustrated in Figure 3.14.

Loudness

Loudness is a subjective experience, as contrasted with the purely physical force of intensity. The thinking reader has realized, to be sure, that a relationship exists between increased intensity and increased loudness. The decibel, however, is not a unit of loudness measurement, and thus such statements as “The noise in this room is 60 dB loud” are erroneous. The duration and frequency of sounds contribute to the sensation of loudness.

14. The psychological correlate of frequency is _____.

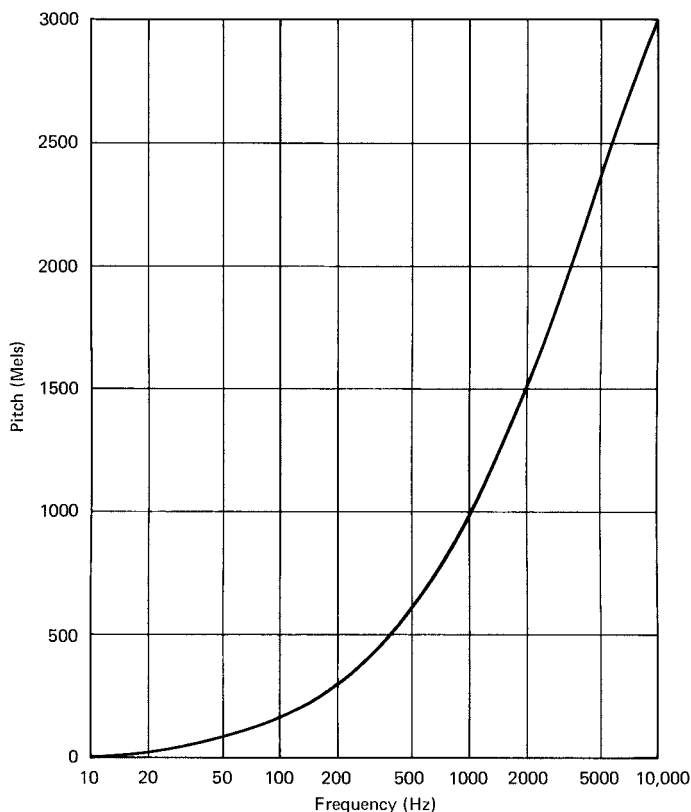


FIGURE 3.14 The mel scale, showing the relationship between pitch (in mels) and frequency (in hertz).

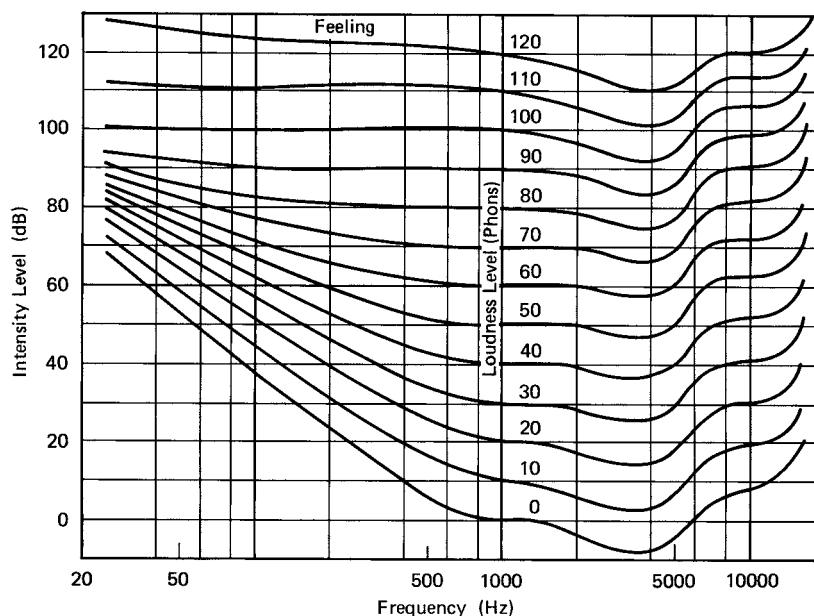


FIGURE 3.15 Equal loudness contours showing the relationship between loudness level (in phons) and intensity (in dB) as a function of frequency.

As stated earlier, the ear is not equally sensitive at all frequencies. It is also true that the subjective experience of loudness changes at different frequencies. Comparing the loudness of different frequencies to the loudness of a 1000 Hz tone at a number of intensity levels determines the **loudness level** of the different frequencies. Figure 3.15 shows that loudness grows faster for low-frequency tones and certain high-frequency tones than for mid-frequencies. The unit of loudness level is the **phon**.

The term **sone** refers to the comparison of the loudness of a 1000 Hz tone at different intensities. One sone is the loudness of 1000 Hz at 40 dB SL. The intensity required for subjects to perceive half the loudness of 1 sone is 0.5 sones; the intensity for twice the loudness is 2 sones, and so forth. Loudness level (in phons) can be related to loudness (in sones) but, as Figure 3.16 shows, the measurements do not correspond precisely.

Localization

Hearing is a distance sense, unaffected by many barriers that interfere with sight, touch, and smell. Sound can bend around corners with little distortion, although as frequencies get higher, they become more unidirectional. Under many conditions it is possible, even without seeing the source of a sound, to tell the direction from which it comes. This ability, called **localization**, is a complex phenomenon resulting from the interaction of both ears. The localization of sound, which warned our ancestors of possible danger, was probably a major contributor to the early survival of our species.

Localization is possible because of the relative intensities of sounds and their times of arrival at the two ears (i.e., phase). The greatest single contributors to our ability to

15. The ability to localize sound requires that the individual have

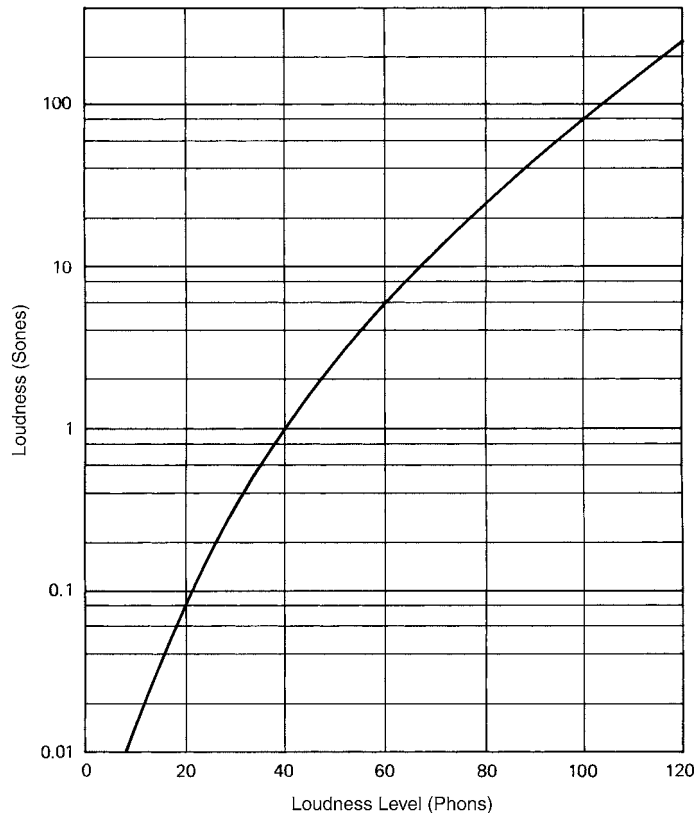


FIGURE 3.16 Loudness function showing the relationship between loudness (in sones) and loudness level (in phons).

localize are interaural phase differences in the low frequencies (below 1500 Hz) and intensity differences in the higher frequencies. Naturally, in an acoustical environment with hard surfaces, **reverberation** may occur, and the sound may be perceived to come from a direction other than its source. An area in which there are no hard surfaces to cause reverberation is called a **free field**. Free fields actually exist only in such exotic areas as mountaintops and specially built **anechoic chambers** (Figure 3.17).

Masking

When two sounds are heard simultaneously, the intensity of one sound may be sufficient to cause the other to be inaudible. This change in the threshold of a sound caused by a second sound with which it coexists is called **masking**. There is surely no one who has not experienced masking in noisy situations in the form of speech interference. The noise that causes the interference is called the masker. Because masking plays an important role in some aspects of clinical audiology, it is discussed in detail in subsequent chapters of this book.

16. The threshold shift of one sound that is caused by the introduction of a second sound is called _____.

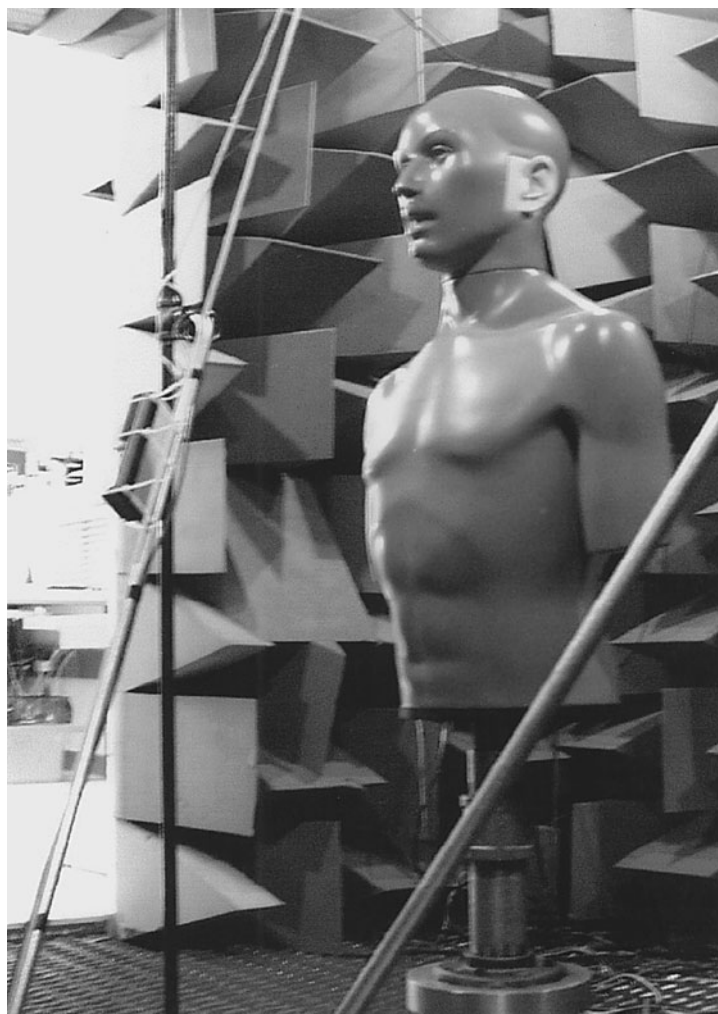


FIGURE 3.17 The inside of an anechoic chamber designed to eliminate sound reverberation. KEMAR (Knowles Electronic Manikin for Acoustic Research) is designed with physical dimensions and properties that mimic the average adult male. The manikin with its built-in ear simulator within the manikin's canal is frequently used in hearing-aid research. (Courtesy of Etymotic Research)

Impedance

Any moving object must overcome a certain amount of **resistance** to its movement. A sound wave moving through air will strike surfaces that impede or retard its progress. The **impedance** of a medium is the opposition it offers to the transmission of acoustic energy.

As a general rule, as a surface that is placed in the path of a sound wave is made more dense, it offers greater impedance to the wave. For example, when a sound strikes a closed door, some of the energy will be reflected because the door is so much denser than the air on either side of it. If the sound is to be carried to the adjacent room, the door itself must be set into vibration, whereupon the opposite side of the door, moving against the air molecules in the next room, generates new sound waves. The amount of impedance of the door will determine the amplitude of the waves in the next room. The greater the impedance of the door, the smaller the amplitude of the waves transmitted to the adjacent room.

Given sufficient energy to overcome its inertia, a mass may be set into vibration. The resonant characteristics of a body or medium determine its frequencies of most efficient and least efficient vibration. **Resonance** is determined by the mass, elasticity, and frictional characteristics of

an object (or medium). Therefore, resonance characteristics are defined by impedance. In the case of sound moving past an object, like a door, there will be more impedance to some frequencies than to others. As a rule, the mass of the door will attenuate high-frequency sounds more than low-frequency sounds, which is what makes the sound on the opposite side of the door appear muffled.

Total impedance (Z) is determined by two factors. The first is simple resistance (R)—that is, resistance that is not influenced by frequency of vibration. This simple resistance is analogous to electrical resistance in a direct-current system, such as a battery, in which electrons move in a single direction from a negative to a positive pole. The second factor is complex resistance, or **reactance**. Reactance is influenced by frequency, so that the opposition to energy transfer varies with frequency. Reactance is seen in alternating-current electrical systems, such as household current, in which the flow of electrons is periodically reversed (60 Hz in the United States).

Total reactance is determined by two subsidiary factors called **mass reactance** and **stiffness reactance**. As either the physical mass (M) of an object or the frequency (f) at which the object vibrates is increased, so does the mass reactance. In other words, mass reactance is directly related to both mass and frequency. Stiffness (S) reactance behaves in an opposite manner. As the physical stiffness of an object increases, so does stiffness reactance. However, as frequency increases, stiffness reactance decreases (an inverse relationship).

Together, simple resistance, mass reactance, and stiffness reactance all contribute to the determination of total impedance. All four terms are given the same unit of measurement, the **ohm** (Ω).⁹ In the formula for computing impedance, Z is the total impedance, R is the simple resistance, $2\pi fM$ is the mass reactance, and $S/2\pi f$ is the stiffness reactance. This equation shows that mass reactance and stiffness reactance combine algebraically.

$$Z = \sqrt{R^2 + \left(2\pi fM - \frac{S}{2\pi f}\right)^2}$$

Sound Measurement

Audiologists are generally interested in making two kinds of measurements: those of the hearing ability of patients with possible disorders of the auditory system and those of sound-pressure levels in the environment. The first modern step toward quantifying the amount of a patient's hearing loss came with the development of the pure-tone **audiometer**. This device allows for a comparison of any person's hearing threshold to that of an established norm. Hearing threshold is usually defined as the intensity at which a tone is barely audible. Hearing sensitivity is expressed as the number of decibels above (or below) the average normal-hearing person's thresholds for different pure tones (0 dB HL). Speech audiometers were designed, in part, to measure thresholds for the spoken word.

The Pure-Tone Audiometer

A pure-tone audiometer is diagrammed in Figure 3.18. It consists of an audio oscillator, which generates pure tones of different frequencies, usually at discrete steps of 125, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, and 8000 Hz. Each tone is amplified to a maximum of about 110 dB HL in the frequency range of 500 to 4000 Hz, with less output above and below those frequencies.

The tones are attenuated with the use of a manual dial or electronic attenuator, which is numbered (contrary to attenuation) in decibels above the normal threshold for each frequency.

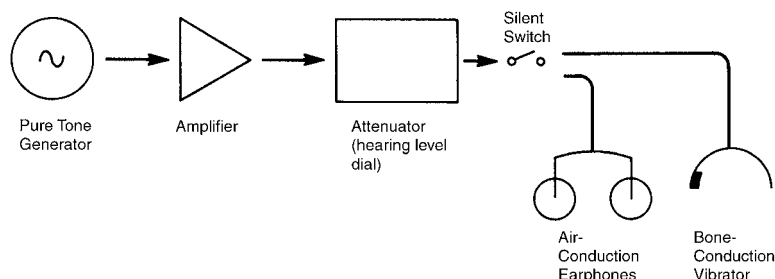


FIGURE 3.18 Block diagram of a pure-tone audiometer.

As the number of decibels is increased, the attenuation is decreased. The audiometer is provided with a silent switch that can introduce or interrupt a tone. The signal is routed, via an output selection control, to a right or left earphone or to a bone-conduction vibrator. A photograph of a pure-tone audiometer is shown in Figure 3.19.

Air Conduction. Earphones are held in place by a steel headband that fits across the top of the head. The phones themselves are connected to the headband by two small metal yokes. The earphone consists of a magnetic device that transduces the electrical translations supplied by the audiometer to a small diaphragm that vibrates according to the acoustic equivalents of frequency and intensity. Around the earphone is a rubber cushion that may fit around the ear (circumaural) or, more usually, over the ear (supra-aural). Circumaural earphones are rarely used with audiometers because they are difficult to calibrate. The movement of the earphone diaphragm generates the sound, which enters the ear directly, resulting in an air-conduction signal. Supra-aural audiometric earphones are shown in Figure 3.20.

17. Audiometer earphones are used to test hearing by _____.



FIGURE 3.19 A pure-tone audiometer designed to deliver preselected frequencies at examiner-selected intensities to determine an individual's hearing sensitivity. (Courtesy of MAICO)



FIGURE 3.20 A set of supra-aural air-conduction receivers.

For some time it has been recognized that there are distinct advantages to using earphones that are inserted into the external ear canal for air-conduction testing. These advantages will be discussed in some detail later in this book, but one of them includes a significant increase in comfort for the patient. Insert earphones that are appropriate for audiometry are shown in Figure 3.21.

Bone Conduction. Selection of the bone-conduction output of the audiometer causes the signal to terminate in a small plastic device with a slight concavity on one side for comfortable fit against the skull. The principle of the bone-conduction vibrator is the same as that of the air-conduction



FIGURE 3.21 A pair of insert receivers. (Courtesy of Etymotic Research)

18. An oscillator is placed on the forehead or mastoid to test hearing by _____.

receiver except that instead of moving a waferlike diaphragm, the plastic shell of the vibrator must be set into motion. Because they must vibrate a greater mass (the skull), bone-conduction vibrators require greater energy than air-conduction receivers to generate a vibration level high enough to stimulate normal hearing. For this reason the maximum power outputs are considerably lower for bone conduction, usually not exceeding 50 to 80 dB HL, depending on frequency. Frequencies of 250 through 4000 Hz are usually available for bone-conduction testing.

The bone-conduction vibrator is held against the skull at either the forehead or the mastoid process. When the forehead is the placement site, a plastic strap is used that circles the head. When the bone behind the ear is the desired place for testing, a spring-steel headband that goes across the top of the skull is employed. A bone-conduction vibrator is shown in Figure 3.22.

The Speech Audiometer

As will be discussed later in this book, measurements made with speech stimuli are very helpful in the diagnosis of auditory disorders. A speech audiometer is required for such measurements. The speech audiometer is usually part of a clinical audiometer (Figure 3.23) that can also perform pure-tone tests.

The diagram in Figure 3.24 shows that the speech circuit of an audiometer can have an input signal provided by a microphone, a compact disc (CD) player, or a tape recorder. The input level of the speech signal is monitored by an averaging voltmeter called a VU (volume units) meter. Such a meter reads in dB VU, implying an electrical reference in watts. The signal is amplified and attenuated as in a pure-tone audiometer, with the hearing-level dial calibrated in decibels with reference to audiometric zero for speech (20 dB SPL on the ANSI-2004 standard for a TDH-49 earphone). Some audiometers use light-emitting diodes in lieu of a VU meter.

Air Conduction. Most of the measurements made on speech audiometers are accomplished through air-conduction receivers. Testing may be carried out by selecting the right ear, the left ear, or both ears. The usual range is from -10 to 110 dB HL.



FIGURE 3.22 A bone-conduction vibrator through which pure tones may be routed using a pure-tone audiometer to measure bone-conduction sensitivity.



FIGURE 3.23 A diagnostic audiometer measures hearing sensitivity for speech and for tones via either air or bone conduction. (Courtesy of Grason-Stadler Co.)

Sound Field. It is often desirable to test with speech in the sound field—that is, to feed the speech signal into the room rather than directly into the ears by using one or more loudspeakers. The signal generated by the audiometer is designed for air-conduction earphones and does not have sufficient power to drive a larger loudspeaker. When the speaker output of the audiometer is selected, the speech signal is fed to an auxiliary amplifier that augments the intensity of the signal, creating the additional power necessary to drive the loudspeaker.

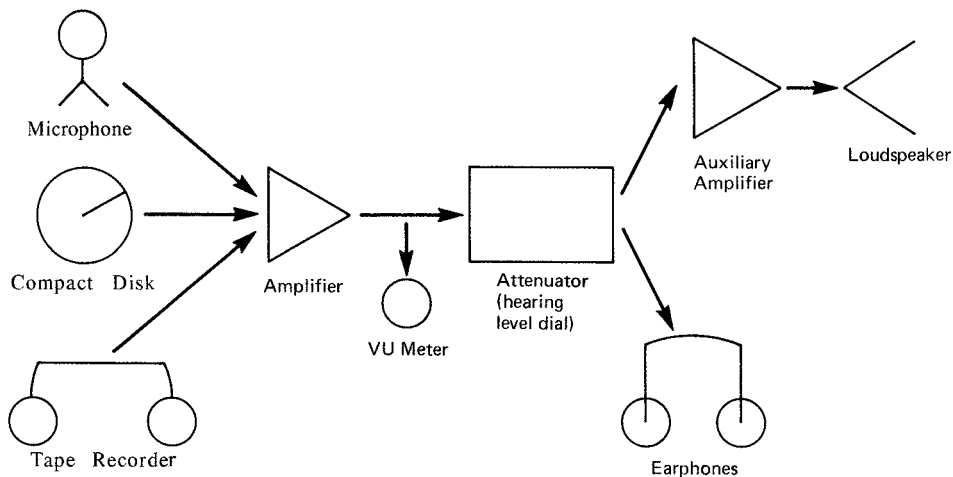


FIGURE 3.24 Block diagram of the speech circuit of a diagnostic audiometer.

Sound-Level Meters

As mentioned earlier, airborne sounds are measured by devices called sound-level meters. These consist of a microphone, amplifier, attenuator, and meter that pick up and transduce pressure waves in the air, measure them electrically, and read out the sound-pressure levels in decibels. The usual reference for sound-level meters is 20 μ Pa.

Because the human ear responds differently to different frequencies, many sound-level meters contain systems called weighting networks, which are filters to alter the response of the instrument, much as the ear does at different levels. The phon lines (Figure 3.15) show that the ear is not very sensitive to low frequencies at low SPLs and that, as the sound increases in intensity, the ear is capable of better and better low frequency response. The three usual weighting networks of sound-level meters are shown in Figure 3.25, which illustrates how the meters respond.

Sound-level meters are useful in the study of acoustics and are common tools in industry as concern over noise pollution grows. Background noise levels can play a major role in the testing of hearing because, if they are sufficiently high, they may interfere with accurate measurement by masking the test stimuli. Whenever hearing testing is undertaken, especially with persons who have normal or near-normal hearing, the background noise levels should be known.

19. The decibel reference used in sound-level meters is _____.

Acceptable Noise Levels for Audiometry

Table 3.4 shows the maximum room noise allowable for air-conduction testing using supra-aural and insert earphones on the ANSI-1999 scale. To determine the allowable levels for bone-conduction testing, the attenuation provided by the usual audiometer earphone and cushion must

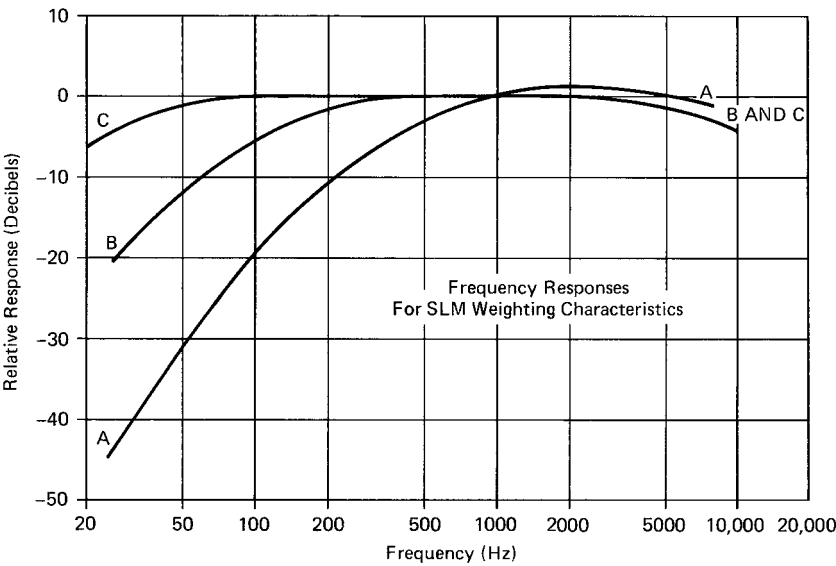


FIGURE 3.25 Weighting networks for sound-level meters.

TABLE 3.4 Maximum Permissible Ambient Noise Sound Pressure Levels in Octave Bands for Audiometric Testing with Ears Covered Using Supra-Aural or Insert Earphones and Test Frequency Ranges 125 to 8000, 250 to 8000, and 500 to 8000 Hz

<i>Octave Band Intervals</i>	<i>Supra-Aural Earphones</i>			<i>Insert Earphones</i>		
	<i>125 to 8000 Hz</i>	<i>250 to 8000 Hz</i>	<i>500 to 8000 Hz</i>	<i>125 to 8000 Hz</i>	<i>250 to 8000 Hz</i>	<i>500 to 8000 Hz</i>
125	35.0	39.0	49.0	59.0	67.0	78.0
250	25.0	25.0	35.0	53.0	53.0	64.0
500	21.0	21.0	21.0	50.0	50.0	50.0
1000	26.0	26.0	26.0	47.0	47.0	47.0
2000	34.0	34.0	34.0	49.0	49.0	49.0
4000	37.0	37.0	37.0	50.0	50.0	50.0
8000	37.0	37.0	37.0	56.0	56.0	56.0

Tabled values are in dB re: 20 μ Pa rounded to the nearest 0.5 dB (ANSI, 1999).

be subtracted from the maximum allowable levels for air conduction because the ear remains uncovered during bone-conduction audiometry.

Calibration of Audiometers

Although periodic factory checks on audiometer calibration are desirable, many audiologists also perform frequent checks on the operation of their equipment on-site in the clinic. In the early days of audiometers, checks on the reliability of the hearing level were conducted by testing a group of subjects with known normal hearing—the “psychoacoustic method.” This is done by taking the median of the threshold findings and posting a correction chart on the audiometer to remind the audiologist to correct any readings obtained on a patient by the number of decibels the audiometer had drifted out of calibration.

Many audiology clinics today are equipped with meters and also couplers, so that the task of level checking may be accomplished electroacoustically. The coupler is often called an **artificial ear** because that is what it is designed to replicate. The earphone is placed over a carefully machined coupler, usually containing a cavity of precisely 6 cm³ to simulate the average volume of air between the earphone and the eardrum membrane. A weight of 500 grams, or a spring with equivalent tension, holds the receiver in place. Sounds emanating from the diaphragm of the receiver are picked up by a sensitive microphone at the bottom of the coupler, amplified, and read in dB SPL on a sound-level meter. To be certain that the meter is reading the level of the tone (or other signal) from the receiver, and not the ambient room noise, the level of the signal is usually high enough to avoid this possibility. Hearing levels of 70 dB are convenient for this purpose, and the readout should correspond to the number of decibels required for threshold of the particular signal (see Table 3.2), plus 70 dB. A form designed for level checking with an artificial ear is shown in Figure 3.26, and a commercial testing unit is shown in Figure 3.27.

Because of differences in size and design, insert earphones cannot be calibrated with a standard 6 cm³ coupler. Rather, a smaller coupler, which has a volume of 2 cm³, is used with the calibration device described earlier. Reference equivalent sound-pressure levels for calibrating insert earphones are shown in Table 3.5.

When calibrating the speech circuit of an audiometer, a signal must be fed through one of the inputs. A pure tone, a noise containing approximately equal intensity at all frequencies, or a

University of Texas Speech and Hearing Center AUDIOMETER CALIBRATION																		
For TDH-49 Earphone					Calibrated By _____ Audiometer _____ Serial No. _____ Date _____													
Frequency					Right Air Output*			Left Air Output*			Mastoid Output #			Forehead Output #				
Obs.	Attn. HL	Err.	Dial	Count	HL	Obs.	Cor.	Err.	Obs.	Cor.	Err.	HL	Obs.	Cor.	Err.	Obs.	Cor.	Err.
	110																	
	105		125		70		117.5			117.5								
	100																	
	95		250		70		96.5			96.5		25		66.4			79.9	
	90																	
	85		500		70		83.5			83.5		40		70.7			85.7	
	80																	
	75		750		70		78.5			78.5		40		59.3			71.8	
	70																	
	65		1000		70		77.5			77.5		40		56.9			66.9	
	60																	
	55		1500		70		77.5			77.5		40		55.4			66.4	
	50																	
	45		2000		70		81.0			81.0		40		48.1			56.6	
	40																	
	35		3000		70		79.5			79.5		40		46.6			54.1	
	30																	
	25		4000		70		80.5			80.5		40		51.2			57.7	
	20																	
	15		6000		70		83.5			83.5								
	10																	
	5		8000		70		83.0			83.0								
	0																	
	Ttl Err.		Speech		70		90.0			90.0		40		()			()	

FUNCTIONAL CHECKS WITH TOLERANCES:

Rise Time (20 — 100 milliseconds) _____ .

Fall Time (5 — 100 milliseconds) _____ .

Overshoot and ringing ($\pm$ 1dB) _____ .

Total Harmonic Distortion (max. -30dB) _____ .

Comments: _____

***Figures in this column are dB re 20 μ Pa for proposed ANSI standards for use with TDH-49 receivers mounted in MX-41/AR cushions.**

#These figures include corrections for the B&K Model 4930 artificial mastoid for a B-70A bone-conduction vibrator.

FNM/80

FIGURE 3.26 Sample of form for field check of audiometer level and frequency.



FIGURE 3.27 A commercial audiometer calibration device. A supra-aural earphone is placed on an artificial ear for calibration. A separate, smaller-sized, artificial ear is used for calibration of insert receivers. (Courtesy Larson-Davis Laboratory, a Division of PCB Piezotronics, Inc.)

TABLE 3.5 Reference Equivalent Threshold Sound Pressure Levels (RETSPLs) (dB re 20 μ Pa) for Calibration of Insert Earphones to the ANSI (2004) Standard

Frequency (Hz)	Occluded Ear Simulator	HA-2 with Rigid Tube	HA-1
125	28.0	26.0	26.5
160	24.5	22.0	22.0
200	21.5	18.0	19.5
250	17.5	14.0	14.5
315	15.5	12.0	15.0
400	13.0	9.0	10.5
500	9.5	5.5	6.0
630	7.5	4.0	4.5
750	6.0	2.0	2.0
800	5.5	1.5	1.5
1000	5.5	0.0	0.0
1250	8.5	2.0	1.0
1500	9.5	2.0	0.0
1600	9.5	2.0	1.5
2000	11.5	3.0	2.5
2500	13.5	5.0	4.5
3000	13.0	3.5	2.5
3150	13.0	4.0	2.5
4000	15.0	5.5	0.0
5000	18.5	5.0	1.5
6000	16.0	2.0	-2.5
6300	16.0	2.0	-2.0
8000	15.5	0.0	-3.5
Speech	18.0	12.5	12.5

sustained vowel sound, may be used. The signal is adjusted so that the VU or equivalent meter reads zero. With the hearing-level dial set at 70 dB, and with the earphone on the coupler, the signal should read 90 dB SPL on the meter (70 dB HL plus 20 dB SPL required for audiometric zero for speech) for the most commonly used earphone.

Calibration of the bone-conduction systems of audiometers may be accomplished in several ways. One method of field calibration involves the use of several patients with known sensory/neural losses. Their air- and bone-conduction thresholds are compared, and median values for the differences are taken at each frequency. The amounts by which the bone-conduction thresholds differ from the (calibrated) air-conduction thresholds are averaged, and corrections are posted on the audiometer. Persons with normal hearing cannot be used because of the danger of masking their uncovered ears by ambient room noise.

The **artificial mastoid** (Figure 3.28) is a device that allows for electronic calibration of the bone-conduction system of an audiometer. The procedure is similar to that for testing air-conduction calibration. The bone-conduction vibrator is placed on the artificial mastoid, which has properties similar to the human skull, scalp, and skin. Vibrations are transduced into electrical currents, which are then converted to decibels for direct readout. The form shown in Figure 3.26 allows for calibration to the ANSI standard for bone-conduction testing on either the forehead or the mastoid. The reference equivalent threshold force levels (RETFLs) are shown in Table 3.6.

Calibration of a loudspeaker system with an audiometer requires either the testing of a number of normal-hearing subjects or the use of a sound-level meter. A heavy chair that is difficult to move should be placed before the speaker at a distance of about three times the diameter of the loudspeaker, plus one foot, or often just at one meter. This allows the subject to be placed in the “far field.” The sound-level meter should be placed in the same position as the head of a patient seated in that same chair.

The loudspeaker output for 0 dB HL in the sound field, when listening with both ears, should be 14.5 dB SPL for speech. If the hearing-level dial is set to 70 dB, the sound-level meter should read 70 dB, plus 20 dB for audiometric zero for speech, minus 5.5 dB (84.5 dB SPL). Five and one-half decibels are subtracted because thresholds for pure tones determined under earphones, called the minimum audible pressure (MAP) (Sivian & White, 1933), are slightly higher (require greater intensity) than thresholds determined in a free sound field, the minimum audible field (MAF) (Fletcher & Munson, 1933). When an external auxiliary amplifier is used to power the loudspeaker,



FIGURE 3.28 An artificial mastoid assembly for calibration of the bone-conduction system of an audiometer. The artificial mastoid has properties similar to the human skull, scalp, and skin. Here the bone-conduction vibrator of an audiometer is placed on the artificial mastoid, which will then be attached to the audiometer calibration device. (Courtesy Larson-Davis Laboratory, a Division of PCB Piezotronics, Inc.)

TABLE 3.6 Reference Equivalent Threshold Force Levels (RETFLs) for Bone Vibrators

<i>Frequency Hz</i>	<i>Mastoid (dB re 1μN)</i>	<i>Forehead (dB re 1μN)</i>	<i>Forehead Minus Mastoid</i>
250	67.0	79.0	12.0
315	64.0	76.5	12.5
400	61.0	74.5	13.5
500	58.0	72.0	14.0
630	52.5	66.0	13.5
750	48.5	61.5	13.0
800	47.0	59.0	12.0
1000	42.5	51.0	8.5
1250	39.0	49.0	10.0
1500	36.5	47.5	11.0
1600	35.5	46.5	11.0
2000	31.0	42.5	11.5
2500	29.5	41.5	12.0
3000	30.0	42.0	12.0
3150	31.0	42.5	11.5
4000	35.5	43.5	8.0
5000	40.0	51.0	11.0
6000	40.0	51.0	11.0
6300	40.0	50.0	10.0
8000	40.0	50.0	10.0
Speech	55.0	63.5	8.5

(ANSI, 2004)

its volume control may often be adjusted to produce the proper level. Many modern diagnostic audiometers contain their own “booster” amplifiers and cannot be easily adjusted in the field. Reference equivalent sound-pressure levels for sound-field testing are shown in Table 3.7.

Whenever the audiometer differs from the required level at any frequency by more than 2.5 dB, a correction should be added to the hearing-level dial setting during audiometric testing. Corrections are rounded out to the nearest multiple of 5 dB. Although this may seem superficially illogical, if the calibration procedure reveals that the system is putting out too low a level, the number of decibels of deviation must be subtracted from the hearing-level dial setting during any given test. If the intensity is too high, the correction is added during testing. Whenever level calibration reveals marked differences from specification, the audiometer should be sent for recalibration. Audiologists should never assume that their audiometers are in proper calibration, even new units, unless they have verified this for themselves.

In addition to level checking, on pure-tone audiometers it is important to check for changes in frequency to be sure that the ANSI frequency limitations have not been exceeded. This may be done with a frequency counter.

The linearity of the attenuator dial is most easily tested electronically with a voltmeter. Checks should be made through the entire intensity range to be certain that when the hearing-level dial is moved a given number of decibels, the level actually changes by this precise amount, plus or minus the stated tolerance per 5 dB step. In addition, the total error in the hearing-level dial linearity cannot exceed a set degree of error, depending on frequency. The form shown in Figure 3.26 provides space for checking attenuator linearity.

Even though the audiometer generates a pure tone, it is likely that distortion in the system (often the earphone) will result in the emission of the second harmonic of the tone; that is, if a

TABLE 3.7 Reference Equivalent Threshold Sound Pressure Levels (RETSPLs) (dB re 20 μ Pa) for Sound-Field Testing (ANSI, 2004)

Frequency (Hz)	Binaural Listening ^a in Free Field	Monaural Listening in Free Field		
	0 Degree Incidence	0 Degree Incidence	45 Degree Incidence	90 Degree Incidence
125	22.0	24.0	23.5	23.0
160	18.0	20.0	19.0	18.5
200	14.5	16.5	15.5	15.0
250	11.0	13.0	12.0	11.0
315	8.5	10.5	9.0	8.0
400	6.0	8.0	5.5	4.5
500	4.0	6.0	3.0	1.5
630	2.5	4.5	1.0	-0.5
750	2.0	4.0	0.5	-1.0
800	2.0	4.0	0.5	-1.0
1000	2.0	4.0	0.0	-1.5
1250	1.5	3.5	-0.5	-2.5
1500	0.5	2.5	-1.0	-2.5
1600	0.0	2.0	-1.5	-2.5
2000	-1.5	0.5	-2.5	-1.5
2500	-4.0	-2.0	-5.5	-4.0
3000	-6.0	-4.0	-9.0	-6.5
3150	-6.5	-4.5	-9.5	-6.5
4000	-6.5	-4.5	-8.5	-4.0
5000	-3.0	-1.0	-7.0	-5.0
6000	2.5	4.5	-3.0	-5.0
6300	4.0	6.0	-1.5	-4.0
8000	11.5	13.5	8.0	5.5
9000	13.5	15.5	10.5	8.5
10000	13.5	15.5	11.0	9.5
11200	12.0	14.0	10.0	7.0
12500	11.0	13.0	11.5	5.0
14000	16.0	18.0		
16000	43.5	44.5		
Speech	14.5	16.5	12.5	11.0

^aISO 389-7 Reference Threshold of Hearing Under Free Field and Diffuse Field Conditions (ANSI, 2004).

1000 Hz tone is generated, some energy at 2000 Hz will be present. ANSI standards state how much lower the second harmonic must be relative to the fundamental (the test frequency) to meet tolerance. This can be checked with special equipment, such as frequency counters.

Summary

Sound may be regarded objectively if we consider its waves in terms of their frequency, intensity, phase, and spectrum. Sounds may also be studied subjectively, in terms of pitch, loudness, or the interactions of signals producing masking or localization. In discussing sound energy, it is always important to specify precisely the various aspects and appropriate measurement references, such as hertz, decibels (IL, SPL, HL, or SL), mels, sones, or phons.

REVIEW TABLE 3.1 Common Units of Measurement in Acoustics

<i>Measurement</i>	<i>Unit</i>		<i>Abbreviation</i>		
	<i>CGS</i>	<i>SI</i>	<i>CGS</i>	<i>SI</i>	<i>Equivalents</i>
Length	Centimeter	Meter	cm	m	1 cm = 0.01 m 1 m = 100 cm
Mass	Gram	Kilogram	g	kg	1 g = 0.001 kg 1 kg = 1000 g
Area	Square centimeter	Square meter	cm ²	m ²	1 cm ² = 0.0001 m ² 1 m ² = 10,000 cm ²
Work	Erg	Joule	e	J	1 e = 0.0000001 J 1 J = 10,000,000 e
Power	Ergs per second	Joules per second	e/sec	J/sec	1 e/sec = 0.0000001 J/sec 1 J/sec = 10,000,000 e/sec
	Watts	Watts	w	w	1 w = 1 J/sec 1 w = 10,000,000 e/sec
Force	Dyne	Newton	d	N	1 d = 0.00001 N 1 N = 100,000 d
Intensity	Watts per centimeter squared	Watts per meter squared	w/cm ²	w/m ²	1 w/cm ² = 10,000 w/m ² 1 w/m ² = 0.0001 w/cm ²
Pressure	Dynes per centimeter squared	* Newtons per meter squared	d/cm ²	N/m ²	1 d/cm ² = 0.1 Pa
		Pascal		Pa	1 Pa = 10 d/cm ² 1 Pa = 1 N/m ²
Speed (velocity)	Centimeters per second	Meters per second	cm/sec	m/sec	1 cm/sec = 0.01 m/sec 1 m/sec = 100 cm/sec
Acceleration	Centimeters per second squared	Meters per second squared	cm/sec ²	m/sec ²	1 cm/sec ² = 0.01 m/sec ² 1 m/sec ² = 100 cm/sec ²

*Related to but not strictly on the SI scale.

REVIEW TABLE 3.2 Factors Contributing to Psychological Perceptions of Sound

<i>Percept</i>	<i>Prime Determinant</i>	<i>Other Determinants</i>
Pitch	Frequency	Intensity
Loudness	Intensity	Frequency, duration
Quality	Spectrum	

REVIEW TABLE 3.3 Psychological Measurements of Sound

<i>Measurement</i>	<i>Unit</i>	<i>Reference</i>	<i>Physical Correlate</i>
Pitch	Mel	1000 mels (1000 Hz at 40 dB SL)	Frequency
Loudness	Sone	1 sone (1000 Hz at 40 dB SL)	Intensity
Loudness level	Phon	0 phons (corresponding to threshold at 1000 Hz)	Intensity
Quality			Spectrum

REVIEW TABLE 3.4 Physical Measurements of Sound

Measurement	Unit	Reference	Formula	Psychological Correlate
Frequency	cps/Hz			Pitch
Intensity level	dB IL	10^{-16} watt/cm (CGS) 10^{-12} watt/m ² (SI)	$NdB = 10 \log I_O/I_R$	Loudness
Sound-pressure level	dB SPL	0.0002 dyne/cm ² (CGS) 20 μ Pa (SI)	$NdB = 20 \log P_O/P_R$	Loudness
Hearing level	dB HL	ANSI - 2004	$NdB = 20 \log P_O/P_R$	Loudness
Sensation level	dB SL	Hearing threshold of subject	$NdB = 20 \log P_O/P_R$	Loudness
Impedance	ohm		$Z = \sqrt{R^2 + (2\pi fM - S/2\pi f)^2}$	

Study Questions

1. What is wrong with the statement "The signal has a loudness of 40 dB"?
2. Why may two complex waves with components of identical frequency have different waveforms?
3. What determines the frequency of vibration of a mass?
4. List ten units of sound measurement. Describe what they measure and their references when applicable.
5. Give examples of periodic and aperiodic sounds.
6. Explain why two sounds with SPLs of 60 dB each do not total 120 dB when presented simultaneously. What is the total SPL and why?
7. How is audiometer-level calibration accomplished for air conduction, bone conduction, speech, and sound field?
8. Define the threshold of a sound.
9. What is the number of dB IL with a power output of 10^{-1} watt/m²? What is the number of dB SPL with a pressure output of $2 \times 10^4 \mu$ Pa? Check your answers in Table 3.1 and generate more problems if you did not answer these correctly.
10. List the factors that contribute to acoustic impedance.

Suggested Readings

- Frank, T. (2007). Basic instrumentation and calibration. In R. J. Roeser, M. Valente, & H. Hosford-Dunn (Eds.), *Audiology diagnosis* (pp. 195–237). New York: Thieme.
- Hamill, T. A., & Price, L. L. (2007). *The hearing sciences*. San Diego: Plural Publishing.

Endnotes

1. For Robert Brown, British botanist, 1773–1858.
2. In honor of Dr. Heinrich Hertz, German physicist, 1857–1894.
3. Jean Baptiste Joseph Fourier, French mathematician and physicist, 1768–1830.
4. For Sir Isaac Newton, British mathematician, astronomer, and physicist, 1643–1727.
5. For Blaise Pascal, French mathematician and philosopher, 1623–1662.
6. For James Prescott Joule, British physicist, 1818–1889.
7. For James Watt, Scottish inventor, 1736–1819.
8. American of Scottish descent. Renowned educator of children with hearing loss and inventor of the telephone, 1847–1922.
9. For Georg Simon Ohm, German mathematician and physicist, 1787–1854.

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- American National Standards Institute. (2004). *American National Standard Specification for Audiometers*. ANSI S3.6-2004. New York: Author.
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PART II

Hearing Assessment

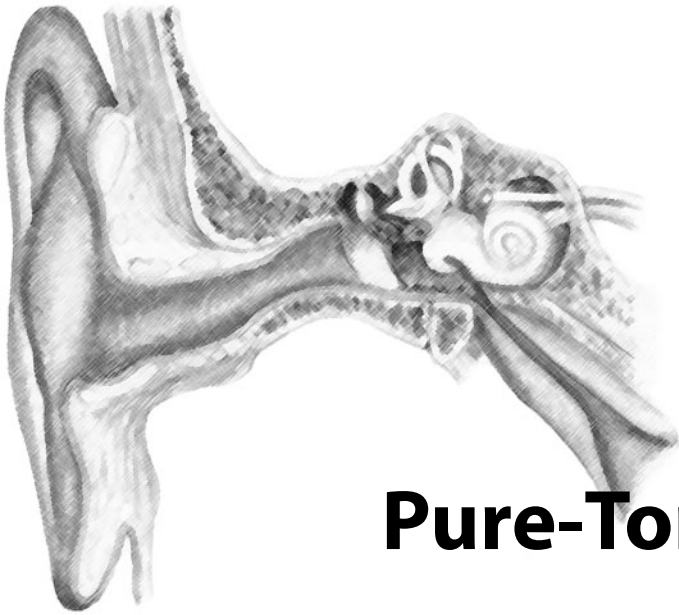


 There is evidence that even seasoned clinicians do not carry out some hearing tests in precise and scientific ways. Often it is the basic tests that do not get the care and attention they deserve. Part II of this book covers the tests that are performed as part of a complete audiological evaluation. Chapter 4 is concerned with pure-tone tests, which are, in some ways, quantifications of the results found on the tuning-fork tests described in Chapter 2. Chapter 5 presents different forms of speech audiometry and describes ways in which tests carried out with speech stimuli assist in diagnosis and treatment. Determination of the need for and appropriate use of masking are described in Chapter 6. Tests for determining the sites in the auditory system that produce different kinds of auditory disorders are described in Chapter 7. These tests include both electrophysiological and electroacoustical procedures, wherein relatively objective determinations can be made of a lesion site, and behavioral measures, in which the patient plays an active role. In many cases, step-by-step procedures are outlined, along with test interpretations. Special diagnostic procedures for testing children are described in Chapter 8. The importance of using an entire battery of tests in making a diagnosis is stressed.

Any test must be subjected to scrutiny to determine its specific usefulness in a particular situation. Questions arise about two factors—reliability and validity. *Reliability* has to do with how well a test result is repeatable. Poor reliability can make a test useless, but good reliability does not necessarily make it valuable unless it is also valid. Questions of *validity* ask whether a test measures what it is supposed to measure. Any single test will turn out in one of four ways:

1. *True positive*: The test indicates a disorder correctly.
2. *True negative*: The test correctly eliminates an incorrect diagnosis.
3. *False positive*: The test suggests a diagnosis incorrectly.
4. *False negative*: The test incorrectly eliminates a correct diagnosis.

Audiological tests can be subjected to a set of mathematical models by **clinical decision analysis (CDA)**. The CDA asks questions about each test's **sensitivity** (how well it correctly diagnoses disorder—true positive), its **specificity** (the inverse of sensitivity—how well it rejects an incorrect diagnosis—true negative), its **efficiency** (the percentage of false positive and false negative results), and its **predictive value** (the percentage of true positive and true negative results).



Pure-Tone Audiometry

PURE-TONE TESTS OF HEARING, performed with an **audiometer**¹, are electronic tests developed along the same conceptual line as tuning-fork tests such as the Schwabach and Rinne. When such tests are carried out, the procedure is called audiometry. The main disadvantage of the tuning-fork tests is that they are difficult to quantify. That is, although the Schwabach might suggest sensory/neural sensitivity that is poorer than normal, it does not tell how much poorer, although the Rinne might suggest the presence of a conductive component, it does not tell how large that component is.

The purpose of testing hearing is to aid in the process of making decisions regarding the type and extent of a patient's hearing loss. Because some of these decisions may have profound effects on the patient's medical, social, educational, and psychological status, accurate performance and careful interpretation of hearing tests are mandatory. The reliability of any test is based on interrelationships among such factors as calibration of equipment, test environment, patient performance, and examiner sophistication. In the final analysis, it is not hearing that we measure but, rather, responses to a set of acoustic signals that we interpret as representing hearing. The vocabularies in Chapters 2 and 3 are relied upon extensively within this chapter, and the reader is exposed to new concepts and problems. Some of these problems can be solved while others can only be compensated for and understood.

LEARNING OBJECTIVES

Assuming access to an audiometer in good working condition and the opportunity for supervised experience, upon completion of this chapter, the reader should be able to

- Describe the fundamentals underlying pure-tone audiometry and the components of a reliable **audiogram**.
- Demonstrate how different pure-tone tests are performed.
- Interpret several pure-tone tests.



The Pure-Tone Audiometer

Pure-tone audiometers have been in use for nearly a hundred years as devices for determining hearing **thresholds**, which are then compared to established norms at various frequencies. The original audiometers were electrically driven tuning forks that generated a number of pure tones of different frequencies. In later designs the tones were generated electrically. With the advent of the electronic era, audiometers incorporated vacuum tubes, then transistors, and then the integrated circuits of today. Like other electronic items, audiometers vary considerably in cost. Specifications of the American National Standards Institute (ANSI, 2004) are imposed on all audiometers so that price differences should not reflect differences in quality of manufacture or in performance.

A common type of audiometer, which is sometimes portable, tests hearing sensitivity by air conduction and bone conduction. A switch allows for easy selection of pure tones. The testable frequencies for air conduction with these audiometers usually include 125, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, and 8000 Hz. The range of intensities begins at minus 10 dB HL and goes to 110 dB HL at frequencies between 500 and 6000 Hz, with slightly lower maximum values at 125, 250, and 8000 Hz. Some special devices, called “extended high-frequency audiometers” have been devised that test from 8000 to 20,000 Hz and have specific diagnostic value. A matched pair of earphones is provided and an output switch directs the tone to either earphone.

Usually only the range from 250 through 4000 Hz may be tested by bone conduction. The maximum testable hearing level for bone conduction is considerably lower than for air conduction, not exceeding 50 dB at 250 Hz and 70 or 80 dB at 500 Hz and above. Maximum outputs for bone conduction are lower than for air conduction for several reasons. The power required to drive a bone-conduction vibrator is greater than for an air-conduction earphone. Furthermore, when the bone-conduction vibrator is driven at high intensities, harmonic distortion takes place, especially in the low frequencies. High-intensity sounds delivered by a bone-conduction oscillator may result in the patient’s feeling rather than hearing the stimulus. In addition to air- and bone-conduction capability, a **masking** control is usually provided that allows for introduction of a noise to the nontest ear when needed during audiometry. For some audiometers the **masking** noise is not of a specific spectrum and is not well calibrated for practical clinical purposes. Persons who rely solely on portable air- and bone-conduction audiometers are

1. The lowest intensity at which a signal can be heard is called the

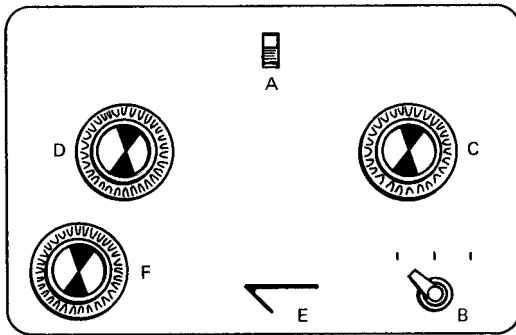


FIGURE 4.1 Typical face of a pure-tone audiometer. (A) On-off power switch. (B) Output selector switch. Selects right ear, left ear, or bone conduction. Masking delivered to nontest earphone for air conduction and to left earphone for bone conduction. (C) Frequency selector dial. Air conduction selects 125, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, or 8000 Hz. Bone conduction selects 250, 500, 750, 1000, 1500, 2000, 3000, or 4000 Hz. (D) Hearing-level dial. Air-conduction range: -10 to 110 dB HL (500 to 6000 Hz), -10 to 90 dB HL (250 and 8000 Hz), and -10 to 80 dB HL (125 Hz). Bone-conduction range: -10 to 50 dB HL (250 Hz), -10 to 70 dB HL (500 Hz), and -10 to 80 dB HL (750 to 4000 Hz). (E) Tone-presentation bar. Introduces tone with prescribed rise and fall time and no audible sound from the switch. (F) Masking-level dial. Controls intensity of masking noise in the nontest ear. Spectrum and intensity range vary with manufacturer.

often unsophisticated about the need for and proper use of masking. Most pure-tone audiometers, however, contain excellent masking-noise generators and can be used for a variety of pure-tone audiometric procedures (Figure 4.1). The reasons for masking and how to accomplish effective masking are discussed in Chapter 6.

Test Environment

Table 3.4 shows the maximum ambient sound-pressure levels allowable for air-conduction and bone-conduction testing. Rooms in which such standards can be met are not always utilized. This is true in the case of hearing test sites in industry or in the public schools. Regardless of the practical limitations imposed by a given situation, the person responsible for audiometric results must realize that background noise may affect audiometric results by elevating auditory thresholds or causing unnecessary screening failures. There are three major ways in which ambient room noise may be attenuated: by using specially designed earphone enclosures, by testing through receivers that insert into the ear, and by using sound-treated chambers.

Earphone Attenuation Devices

Audiometer earphone and cushion combinations do not provide sufficient attenuation of most background noises to allow determination of threshold down to 0 dB HL for people with normal hearing. Several devices are available that allow the supra-aural audiometer earphone and cushion to be mounted within a larger cup, which assists in the attenuation of background noise (see Figure 4.2). Most use a fluid-filled cushion to achieve a tight seal against the head. Such enclosures may be effective but differences exist in the efficiency of different models (Franks, Engel, & Themann, 1992).

Problems with regard to **calibration** are encountered in the use of some earphone enclosures. The phones cannot be placed on the usual 6 cm^3 coupler of an artificial ear. Even if the earphone is checked and found to be in proper calibration before it is placed into the enclosure, mounting may alter the calibration slightly, especially in the low frequencies. Because bone-conduction testing is done with the ears uncovered, the masking effects of room noise may affect these test results without affecting the air-conduction results, possibly causing a misdiagnosis. Children often find these earphone devices heavy and uncomfortable.



FIGURE 4.2 Commercial earphone enclosure device used to attenuate room noise during threshold audiometry. (Audiocups courtesy of Amplivox, Ltd.)

Insert Earphones

Testing hearing with receivers that insert directly into the ear has a number of advantages audiometrically, including further reduction of background noise compared to supra-aural earphones and better infection control because the inserts are disposed of following testing. If the foam is inserted deep into the ear, just short of causing discomfort, even more attenuation is obtained. It is desirable to have patients open and close their mouths three or four times to ensure proper seating of the cushion. Insert earphones can be used for testing children as well as adults. Problems with room-noise masking remain unsolved for bone-conduction testing, even if insert earphones are used for air conduction.

Clinical Commentary

During all patient contact for hearing testing and subsequent treatment, audiologists should be conscious of effective infection-control procedures. Harmful organisms can be passed from person to person through direct patient contact or indirect contact when test instruments are used without proper cleaning. The importance of this area of clinical care cannot be overemphasized.



The American Academy of Audiology's recommended protocol for infection control within audiological practice may be found in the Professional Resources section of the Companion Website.

Sound-Isolated Chambers

The term “soundproof room” is often used erroneously. Totally soundproofing a room—that is, removing all sound—is impossible. All that is necessary in clinical audiometry is to keep the noise in the room below the level of masking that would cause a threshold shift in persons with normal hearing. Sound-isolated rooms may be custom built or purchased commercially in a prefabricated form.

The primary objective in sound-treating a room is to isolate it acoustically from the rest of the building in which it is housed. This usually involves the use of mass (such as cinder blocks), insulating materials (such as fiberglass), and dead air spaces. The door must be solid and must close with a tight acoustic seal. Sometimes two doors are used, one opening into the room and the other opening out. The inside walls are covered with soft materials, such as acoustic tile, to help minimize reverberation. Some such chambers contain large wedge-shaped pieces of soft material such as fiberglass on all walls, ceilings, and floors, with a catwalk provided for the subject. Rooms in which reverberation is markedly diminished are called anechoic chambers. An example of such a room is shown in Figure 3.17.

Audiometric suites may be designed for either one-room or two-room use. In the one-room arrangement, examiners, their equipment, and the patient are all together in the same room, or the patient is within the room and the clinician just outside. In the two-room arrangement, the examiner and audiometer are in the equipment room and the patient is in the examining room. Windows provide visual communication between the rooms. As a rule there are several panes of glass to attenuate the sounds that emanate from the equipment room. Moisture-absorbing materials must be placed between the panes of glass to keep the windows from fogging. Electrical connections between the rooms are necessary so that signals can be directed from the audiometer to the earphones. In addition, a talkback device, consisting of a microphone, amplifier, and speaker and/or earphone, enables the examiner to hear patients when they speak.

In customizing sound-isolated rooms, a great deal of attention is often paid to attenuating sound from adjoining spaces outside the walls of the room, but insufficient care is given to building-borne vibrations that may enter the room from the floor or ceiling. It does little good to have four-foot walls of solid concrete when footsteps can be heard from the floor above.

2. The most popular method of achieving noise levels low enough for audiometric testing is _____.

When sufficient space, money, and architectural know-how are available, custom sound rooms may be the proper choice. Contemporary audiology centers, however, lean more toward the commercially prefabricated sound room, which is made of steel panels and can be installed with wiring included for a two-room operation (Figure 4.3). The manufacturer does not guarantee the noise level within the sound room after installation, but only the amount of attenuation the room will provide under specific laboratory conditions, a fact often not fully understood by many purchasers. It is therefore necessary to prepare the room that will enclose the prefabricated booth by making this area as quiet and nonreverberant as possible.

Prefabricated sound booths are available in one- and two-room suites. Windows with several panes of glass are installed to enable the examiner to observe the patient. The inside walls of the booth are constructed of perforated steel and filled with sound-absorbing materials. Some booths are double-walled; that is, there is one booth inside another, larger one. Prefabricated booths are freestanding, touching none of the walls of the room in which they stand, and are isolated from the ceiling by air and from the floor by specially constructed sound rails.

One of the great weaknesses of audiometric rooms, whether custom or commercial, is their ventilation systems. Rooms that are to be tightly closed must have adequate air circulation, requiring the use of fans and motors. Sometimes the air-intake system is coupled directly with the heating and air-conditioning ducts of the building. In such cases, care must be taken to minimize the introduction of noise through the ventilation system.

Lighting for both kinds of rooms should be incandescent, but if the use of fluorescent lighting is desired, the starters must be remotely mounted. Starters for fluorescent tubes often put out an annoying 60 Hz hum that can be heard by the patient or picked up by the audiometer.



FIGURE 4.3 A commercial double-room sound-treated audiometric test chamber in use.

The Patient's Role in Manual Pure-Tone Audiometry

Patients seeking hearing tests vary a great deal in age, intelligence, education, motivation, and willingness to cooperate. The approach to testing will be very different for an adult than for a child, or for an interested person than for one who is frightened, shy, or even hostile. Procedures also vary depending on the degree of the patient's spoken language skills and if the patient and examiner share a common language. Test results are most easily obtained when a set of instructions can be given orally to a patient, who then complies. As any experienced audiologist will testify, things do not go equally well with all patients.

In pure-tone audiometry, regardless of how the message is conveyed, patients must learn to accept their responsibility in the test if results are to be valid. Spoken instructions, written instructions, gestures, and/or demonstrations may be required. In any case, patients must become aware that they are to indicate when they hear a tone, even when that tone is very soft. The level at which tones are perceived as barely audible is the threshold of hearing sensitivity. Auditory thresholds at different frequencies form the basis for pure-tone audiometry.

Patient Response

After patients understand the instructions and know what they are listening for, they must be given some way of indicating that they have heard. Some audiologists request that patients raise one hand when a tone is heard. They then lower the hand when they no longer hear the tone.

Sometimes patients are asked to raise their right hands when they hear the tone in the right ear and their left hands when they hear the tone in the left ear. The hand signal is probably the most popular response system used in pure-tone audiometry. Many audiologists like this method because they can observe both *how* the patient responds and the hearing level that produces the response. Often, when the tones are close to threshold, patients will raise their hands more hesitatingly than when they are clearly audible. Problems occur with this response system when patients either forget to lower their hands or keep them partially elevated.

As with the hand signal, patients may simply raise one index finger when the tone is heard and lower it when it is not heard. This system has the same advantages and disadvantages as the hand-signal system. It is sometimes difficult, however, to see from an adjacent control room when the patient raises only a finger.

The patient may be given a signal button with instructions to press it when the tone is heard and release it when the tone goes off. Pressing the button illuminates a light on the control panel of the audiometer and/or makes a sound. The use of signal buttons limits the kind of subjective information the audiologist may glean from observing hand or finger signals because the pushbutton is an all-or-none type of response. Reaction time is sometimes another important drawback to pushbutton signaling, as some people may be slow in pushing and releasing the button. Often, if the button is tapped very lightly, the panel light may only flicker, and the response may be missed. Pushbuttons are usually not a good idea for children or the physically disabled, although they are standard equipment on many audiometers. For young adults, however, research does suggest a slight decrease in the length of testing and a patient preference for the use of pushbuttons (DiGiovanni and Repka, 2007).

Some audiologists prefer vocal responses like “now,” “yes,” or “I hear it,” whenever the tone is heard. This procedure is often useful with children, although some patients have complained that their own voices “ring” in the earphones after each utterance, making tones close to threshold difficult to hear. Play and other motivational techniques are often necessary when testing children or other difficult-to-test persons. Some of these methods are discussed in the chapter on pediatric audiology (Chapter 8).

3. True/False

The precise method by which patients signal that they have heard a pure tone is less important than one that produces reliable results.

For a demonstration of a pure-tone air-conduction test, see the video titled “Air-Conduction Testing” in the Clinical Demonstrations section on the Companion Website.



False Responses

False responses are common during behavioral audiometry, and the alert clinician is always on guard for them because they can be misleading and can cause serious errors in the interpretation of test results. A common kind of false response occurs when patients fail to indicate that they have heard a tone. Some patients may have misunderstood, or forgotten, their roles in the test. Such **false negative responses**, which tend to suggest that hearing is worse than it actually is, are also seen in patients who deliberately feign or exaggerate a hearing loss (see Chapter 13).

False positive responses, where the patient responds when no tone has been presented, are often more irritating to the clinician than are false negatives. Most patients will respond with some false positives if long silent periods occur during the test, especially if

4. A patient who signals that a tone was heard when in fact it was not is giving a _____.

they are highly motivated to respond. When false positive responses obscure accurate test results, the clinician must slow down the test to watch for them, which encourages even more false positives. Sometimes even re-instructing the patient fails to alleviate this vexing situation. Some patients who suffer from ringing sounds in their ears complain that this is often confused with the test tone.

The Clinician's Role in Manual Pure-Tone Audiometry

As stated earlier, the first step in manual pure-tone testing is to make patients aware of their task in the procedure. If verbal instructions are given, they may be something like this:

You are going to hear a series of tones, first in one ear and then in the other. When you hear a tone, no matter how high or low in pitch, and no matter how loud or soft, please signal that you have heard it. Raise your hand when you first hear the tone, and keep it up as long as you hear it. Put your hand down quickly when the tone goes away. Remember to signal every time you hear a tone. Are there any questions?

If a different response system is preferred, it may be substituted. There is an advantage to asking the patient to signal quickly to both the onset and the offset of the tone. This permits two responses to each presentation of the tone to be observed. If the patient responds to both the introduction and the discontinuation of the tone, the acceptance of false responses may be avoided.

There are some distinct advantages to providing written instructions to patients before they undergo a hearing evaluation. These instructions can be mailed so that they can be read at home before patients arrive at the audiology clinic, or they can be provided when the patients check in with the receptionist, to be read while waiting to be seen by the audiologist. In addition to augmenting verbal instructions, printed instructions can be retained by the patient after the appointment to help clarify what the different tests were intended to measure. Printed instructions should never be used to replace verbal instructions.



A sample of patient instructions for the basic test battery may be found on the Companion Website in the Professional Resources section.

Patient's Position During Testing

It is of paramount importance that the patient is never in a position to observe the clinician during pure-tone testing. Even small eye, hand, or arm movements by the clinician may cause patients to signal that they have heard a tone when they have not. In one-room situations, patients should be seated so that they are at right angles to the audiometer (Figure 4.4). Some audiologists prefer to have the patient's back to the audiometer to eliminate any possibility of visual cues; however, this is disconcerting to some patients and eliminates observation of the patient's facial expression, which is often helpful to the audiologist in interpreting responses.

Even if the audiologist and patient are in different rooms, care must be taken to ensure that the patient cannot observe the clinician's movements. Figure 4.5 illustrates one satisfactory arrangement. Of course, the patient must always be clearly observable by the audiologist.

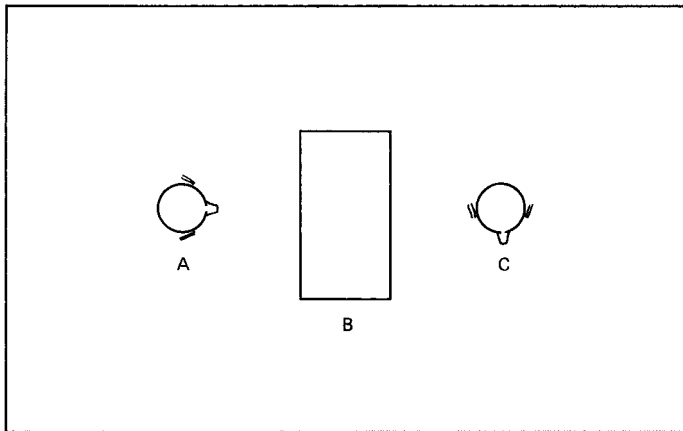


FIGURE 4.4 Proper positioning during pure-tone audiometry carried out with a single sound-treated room for (A) examiner, (B) audiometer, and (C) patient.

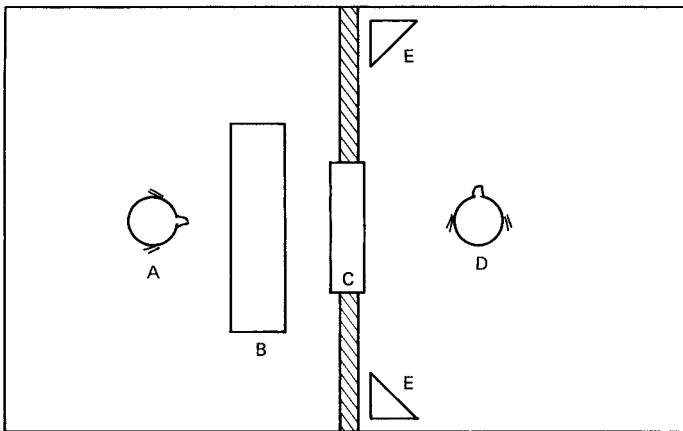


FIGURE 4.5 Proper positioning during pure-tone audiometry conducted in a two-room suite for (A) examiner, (B) audiometer, (C) window separating rooms, (D) patient, and (E) loudspeakers.

Air-Conduction Audiometry

The purpose of air-conduction audiometry is to specify the amount of a patient's hearing sensitivity at various frequencies. If there is a loss of hearing, air-conduction test results can specify the degree of loss but not whether the deficit is produced by abnormality in the conductive mechanism, the sensory/neural mechanism, or both.

Proper placement of supra-aural earphones is shown in Figure 4.6A. The headband should be placed directly over the top of the head. All interfering hair should be pushed out of the way and earrings should be removed, when possible. Eyeglasses should also be removed as they sometimes lift the cushion of the earphone away from the ear and may become uncomfortable as the earphone cushion presses on the temple bar of the eyeglasses. Some patients are reluctant to remove their eyeglasses, as they feel more relaxed when they can see clearly. This is another advantage to insert receivers, which do not interfere at all with the wearing of eyeglasses during testing.

Most earphone cushions are the hard rubber, supra-aural type, fitting tightly against the external ear. The phones should be positioned so that their diaphragms are aimed directly at the opening into the ear canal. The yokes that hold the phones may be pulled down so that the headset is in its most extended position. While the clinician is holding the phones against the ears, the size of the headset can be readjusted for a tight fit. Since this may pull the ear up and cause discomfort, the phones should be gently lifted away from the head and then replaced.



FIGURE 4.6 Properly placed supra-aural (A) and insert (B) air-conduction earphones.

5. Ear canal collapse during audiometry can be avoided with the use of _____.

Some patients' outer ears collapse because of the pressure of the earphones. This creates an artificial conductive hearing loss, usually showing poorer sensitivity in the higher frequencies, which can be misleading in diagnosis. It is advisable to check for ear canal collapse prior to beginning air-conduction testing. This may be accomplished by pressing the **pinna** against the head during ear canal inspection and observing any potential canal-wall collapse. When this occurs, or when the clinician suspects that it may take place because the ear seems particularly supple, certain steps can be taken to overcome the difficulty. One easy solution is to place a small piece of foam rubber (cut in the shape of a behind-the-ear hearing aid) under the pinna (the protrusion of the ear at the side of the head). It is useful to have a number of these small pieces on hand, precut in different sizes for use when they are needed.

Additionally, insert receivers may be used for air-conduction testing when collapsing ear canals are a potential problem. The foam insert must be compressed with the fingers and can be slipped into a small plastic sleeve to maintain this compression until insertion is made into the external ear canal. After the insert is in place, the foam quickly expands. The transducer itself is built within a plastic housing to which the foam tip is attached or is mounted at the end of a 250 mm plastic tube that may be clipped to a blouse or shirt. As with supra-aural phones, insert receivers are colored red and blue for testing the right and left ears, respectively. Properly placed insert earphones are shown in Figure 4.6B.



For a demonstration of the proper placement of supra-aural audiometer earphones and insert audiometer earphones, see the video titled "Air-Conduction Receiver Placement" on the Companion Website.

Procedure for Air-Conduction Audiometry

The selection of which ear to test first is purely arbitrary unless a difference in hearing sensitivity between the ears is known or suspected, in which case the better ear should be tested first.

Frequency order probably does not affect results, although most audiologists prefer to test at 1000 Hz initially, test higher frequencies in ascending order, retest 1000 Hz, and then test lower frequencies in descending order (1000, 2000, 4000, 8000, 1000, 500, 250 Hz, etc.). Some audiologists feel that useful information is gained from the 125 Hz threshold, while others believe that thresholds at this frequency can be predicted from the 250 Hz results.

The audiometric test frequencies may be heard on the accompanying Companion Website under Audiograms in the Learning Supplements section.



Many audiologists sample hearing only at octave points, whereas still others prefer the detail resulting from testing the mid-octave frequencies (750, 1500, 3000, and 6000 Hz). In its guidelines for manual pure-tone audiometry, ASHA (2005) prudently recommends that mid-octave points be tested when a difference of 20 dB or more is seen in the thresholds of adjacent octaves between 500 and 2000 Hz. ASHA also recommends routine testing of the inter-octave frequencies 3000 and 6000 Hz, which frequently turns up notches in the audiogram that would otherwise be missed.

Over the years, a number of different procedures have been devised for determining pure-tone thresholds. Some audiologists have used automatically pulsing tones and some have used manually pulsed tones. Some have used a descending technique, whereby the tone is presented above threshold and lowered in intensity until patients signal that they can no longer hear it. Others have used an ascending approach, increasing the level of the tone from below threshold until a response is given. Still others have used a bracketing procedure to find threshold.

When the profession of audiology was still quite new, Carhart and Jerger (1959) investigated several pure-tone test procedures and found that there were no real differences in results obtained with different methods. Nevertheless, they recommended that a particular procedure be followed, and this procedure appears to have been widely accepted.

The procedure recommended here, based on Carhart and Jerger's suggestion, is to begin testing at 1000 Hz because this frequency is easily heard by most people and has been said to have high test-retest reliability. In practice, it may be advisable in some cases to begin testing at other frequencies, perhaps lower ones, in cases of severe hearing loss in which no measurable hearing may be found at 1000 Hz and above.

Following the ASHA (2005) guidelines, a pure tone is presented initially at 30 dB HL. If a response is obtained, it suggests that the 30 dB tone is above the patient's threshold. If no response is seen, the level is raised to 50 dB HL, introduced, and then raised in 10 dB steps until a response is obtained or the limit of the audiometer is reached for the test frequency.

After a response is obtained, the level is lowered in 10 dB steps. Each time a tone is introduced, it is maintained for one or two seconds. The hearing-level dial is never moved while the tone is in the "on" position, as a scratching sound may occur in the earphone, causing the patient to respond as if to a tone. All ascending movements of the hearing-level dial from this point are made in steps of 5 dB. When the tone is lowered below the patient's response level, it is then raised in 5 dB steps until it is audible again, then lowered in 10 dB steps and raised in 5 dB steps until the 50% threshold response criterion has been met. The threshold is the lowest level at which the patient can correctly identify at least two out of three tone presentations. This usually, but not always, implies that a point 5 dB above this level will evoke more than a 50% response. Levels accepted as threshold are often in the 75% to 100% response range.

Although the majority of audiologists use continuous tones during pure-tone testing, Burk and Wiley (2004) find that automatically pulsed tones have several advantages. The results of tests done using both measures are similar in terms of false responses, test reliability,

6. Traditionally, pure-tone thresholds are obtained by increasing the intensity of the signal in _____ dB steps and decreasing it in _____ dB steps.

and test time. However, test subjects reported increased awareness of the pulsed tones. This study was done on subjects with normal hearing, but it would appear to have some advantages for those with hearing loss, especially those complaining of interfering ear or head noises. For those patients there is also a benefit in using frequency-modulated signals called **warble tones**. Franklin, Johnson, Smith-Olinde, and Nicholson (2009) report findings consistent with past research that there is no significant difference in thresholds obtained with normal hearing listeners regardless of whether the stimulus is a pulsed pure tone or a steady or pulsed warble tone. Caution, however, should be taken when using warble tones with patients who exhibit steeply sloping audiometric curves.

Some audiologists prefer to record the results directly onto a graph called an audiogram, using symbols to depict the threshold of each ear as a function of frequency and intensity (with reference to normal threshold). Others prefer to record their results numerically on a specially prepared score sheet. The form shown in Figure 4.7 has proven to be very useful, especially in the training of new clinicians. This form allows for recording the audiometric data numerically before plotting the graph, for a retest of 1000 Hz, and, if necessary, for retest of all frequencies. Accuracy criteria must be satisfied before the graph is drawn. Some clinics use a form that contains only numerical data and does not employ a graph at all (Figure 4.8). These forms contain space for a number of tests and are useful where serial audiometric data are required.

Any audiometric worksheet should have some minimal identifying information—the patient's name, age, and sex as well as the date of examination, equipment used, and examiner's name. Some estimate of the test reliability should also be noted. After the air-conduction thresholds have been recorded, the average threshold levels for each ear at 500, 1000, and 2000 Hz should be recorded. This is called the **pure-tone average (PTA)**, and it is useful for predicting the threshold for speech as well as for gaining a gross impression of the degree of communication impact imposed by a hearing loss. Table 4.1 shows the degree of communication impact created by various degrees of sensitivity loss. Even though this table is based in part on the recommendations made by Stewart and Downs (1984) for children, it has applications for adults as well. The two-frequency pure-tone average (lowest two thresholds at 500, 1000, and 2000 Hz) may be recorded as well and is often a better predictor of hearing for speech than the three-frequency average. A **variable pure-tone average (VPTA)** (Clark, 1981) consisting of the poorest of three thresholds obtained at 500, 1000, 2000, and 4000 Hz may be more effective than the traditional pure-tone average in estimating the degree of communication impact of a given hearing loss.

Many laypersons are accustomed to expressing the degree of hearing impairment in a percentage because they are unfamiliar with such concepts as frequency and intensity. Many physicians also calculate the percentage of hearing impairment, probably because they believe it is easier for their patients to understand. Although percentage of hearing impairment is an outmoded concept, its continued use mandates mention here; however, for practical application in the counseling of patients, it is considered inappropriate and even misleading in many cases (Clark, 1981, 1982).

One weakness in the concept of percentage of hearing impairment is that it ignores audiometric configuration and looks only at the average hearing loss. The addition of 3000 Hz to the formula by the American Academy of Ophthalmology and Otolaryngology (AAOO) (1979) improves the situation somewhat. The formula, as modified slightly by Sataloff, Sataloff, and Vassallo (1980), works as follows:

1. Compute the average hearing loss (in decibels) from the threshold responses at 500, 1000, 2000, and 3000 Hz for each ear.
2. Subtract 25 dB—considered to be the lower limit of normal hearing by the AAOO.
3. Multiply the remaining number by 1.5% for each ear. This gives the percentage of hearing impairment for each ear.
4. Multiply the percentage of hearing impairment in the better ear by 5, add this figure to the percentage of hearing impairment in the poorer ear, and divide this total by 6. This gives the binaural (both ears) hearing impairment in percentage form.

SERIAL AUDIOMETRIC DATA

Patient's Name _____

		RIGHT EAR							LEFT EAR								
		250	500	1000	2000	3000	4000	8000	250	500	1000	2000	3000	4000	8000		
Date	Air															Air	
	Bone							XXXX							XXXX	Bone	
Date	Air															Air	
	Bone							XXXX							XXXX	Bone	
Date	Air															Air	
	Bone							XXXX							XXXX	Bone	
Date	Air															Air	
	Bone							XXXX							XXXX	Bone	
Date	Air															Air	
	Bone							XXXX							XXXX	Bone	
Date	Air															Air	
	Bone							XXXX							XXXX	Bone	
Date	Air															Air	
	Bone							XXXX							XXXX	Bone	
Date	Air															Air	
	Bone							XXXX							XXXX	Bone	

FIGURE 4.8 A form used to collect serial audiometric data. This allows for recording of ten hearing evaluations so that comparisons may be made to check for progression or improvement of a hearing loss.

TABLE 4.1 Scale of Hearing Impairment Based on the Variable Pure-Tone Average of the Poorest Three Thresholds at 500, 1000, 2000 and 4000 Hz
(Hearing levels refer to the ANSI-2004 scale.)

VPTA (dB)	Degree of Communication Impact	Consider Hearing Aid	Consider Communication Training
–10 to 15	None	No	No
16 to 25	Slight	Possibly, especially for children	Possibly
26 to 40	Mild	Probably for adults, definitely for children	Probably
41 to 55	Moderate	Definitely	Definitely
56 to 70	Moderately Severe	Definitely	Definitely
71 to 90	Severe	Definitely	Definitely
>91	Profound	Consider cochlear implant	Definitely

Obviously, in addition to being somewhat misleading, the computation of percentage of hearing impairment is time-consuming. It is likely that patients are frequently confused by what they have been told about their hearing losses. For example, Table 4.1 indicates that a 25 dB pure-tone average constitutes a slight hearing impairment, but such a loss would prove to be 0% by using the AAOO method, which would suggest to patients that their hearing is normal. Likewise, it can be seen that a 92 dB pure-tone average would be shown as 100% impairment, which would suggest total deafness to many laypersons. Patients with a 92 dB hearing level often prove to have considerable residual hearing.

When an audiogram is used, the graph should conform to specific dimensions. As Figure 4.7 illustrates, frequency (in hertz) is shown on the abscissa and intensity (in dB HL) on the ordinate. The space horizontally for one octave should be the same as the space vertically for 20 dB, forming a perfect square (20 dB by 1 octave). Unlike most graphs, the audiogram is drawn with 0 at the top rather than the bottom. This often leads to confusion for individuals new to the study of audiology since *lower* thresholds (better hearing) are shown by symbols *higher* on the audiogram, and *higher* thresholds (poorer hearing) are shown by symbols *lower* on the audiogram.

7. When properly constructed, the audiogram should show the distance of one octave (across) to be the same as _____ dB down.

After a hearing threshold is obtained, a symbol is placed under the test frequency at a number corresponding to the hearing-level dial setting (in decibels) that represents threshold. The usual symbols for air conduction are a red circle representing the right ear and a blue X representing the left ear. After all the results are plotted on the audiogram, the symbols are usually connected with a solid red line for the right ear and a solid blue line for the left ear. When masking is used in the nontest ear, the symbol Δ (in red) is used for the right ear and the symbol $\square$ (in blue) is used for the left ear.

When no response (NR) is obtained at the highest output for the frequency being tested, the appropriate symbol is placed at the point on the intersection of the maximum testable level for the test frequency; an arrow pointing down indicates no response. Since a significant number of individuals (usually children) have hearing that is more sensitive than the lower limit of intensities shown on standard audiograms (–10 dB HL), Halpin (2007) recommends that an arrow pointing up be placed next to symbols when threshold readings of –10 dB HL are found. This is a logical recommendation.

MODALITY	EAR*		
	RIGHT	BOTH	LEFT
<u>AIR CONDUCTION - EARPHONES</u>			
UNMASKED	○		×
MASKED	△		□
<u>BONE CONDUCTION - MASTOID</u>			
UNMASKED	↗		↘
MASKED	↘		↗
<u>BONE CONDUCTION - FOREHEAD</u>			
UNMASKED		∨	
MASKED	↘		↗
<u>AIR CONDUCTION - SOUND FIELD</u>			
		§	

* The fine vertical lines represent the vertical axis of an audiogram.

MODALITY	EAR*		
	RIGHT	BOTH	LEFT
<u>AIR CONDUCTION - EARPHONES</u>			
UNMASKED	○		×
MASKED	△		□
<u>BONE CONDUCTION - MASTOID</u>			
UNMASKED	<		>
MASKED	□		□
<u>BONE CONDUCTION - FOREHEAD</u>			
UNMASKED		∨	
MASKED	└		┐
<u>AIR CONDUCTION - SOUND FIELD</u>			
		§	

FIGURE 4.9 Symbols recommended by the American Speech-Language-Hearing Association (1990) for use in pure-tone audiometry.

ASHA (1990) has recommended a set of symbols that has been widely adopted. The currently used symbols are shown in Figure 4.9. The obvious reason for using standardized symbols is to improve communication and minimize confusion when audiograms are exchanged among different clinics. Because audiograms are often faxed or photocopied to other clinics many clinicians record their data in black ink. For this reason careful use of the proper symbols is mandated.

Figure 4.10 shows an audiogram that illustrates normal hearing for both ears. Note that the normal audiometric contour is flat because the normal threshold curve, with a sound-pressure-level reference, has been compensated for in calibration of the audiometer, which uses a hearing-level reference.



To see a colored version of an audiogram illustrating normal hearing, look under "Audiograms" in the Learning Supplements section on the Companion Website.

SPEECH AND HEARING CENTER
The University of Texas at Austin 78712
AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐	RIGHT										LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000		
Masking Type WB ☐ NB ☐	5	10	5	5	5	0	10	10	15	10	5	5	10	10	5	15	10	10		
EM Level in Opp. Ear																				

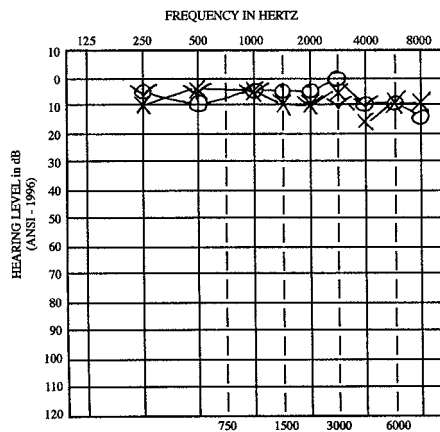
BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT						FOREHEAD						LEFT					
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type WB ☐ NB ☐							5	5	5	10	10	10						
EM Level in Opp. Ear																		

Pure Tone Average	2 Freq	3 Freq	Variable	WEBER						Pure Tone Average	2 Freq	3 Freq	Variable
	5	7	8	M	M	M	M	M	5		7	10	

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☐	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
			List HL	%			List HL	%
EM Level in Opp. Ear								



Speech Presentation

MLV Recorded
SRT ☐ ☐
WRS ☐ ☐
COMMENTS

AUDIOGRAM KEY	
Right	Left
AC Unmasked	AC Masked
BC Mastoid Unmasked	BC Mastoid Masked
BC Forehead Unmasked	BC Forehead Masked
Both	
BC Forehead Unmasked	
Sound Field (unmasked)	
Sound Field (masked)	
Opp. Ear Masked	
Examples of No Response Symbols	

FIGURE 4.10 Audiogram illustrating normal hearing in both ears. Note that no hearing level by either air conduction or bone conduction exceeds 15 dB HL. The three-frequency pure-tone averages are 7 dB HL in each ear. Naturally the two-frequency averages are slightly lower and the variable average slightly higher.

Bone-Conduction Audiometry

The purpose of measuring hearing by bone conduction is to determine the patient's sensory/neural sensitivity. The descriptions offered in Chapter 2 were very much oversimplified, as bone conduction is an extremely complex phenomenon. Actually, hearing by bone conduction arises from the interactions of at least three different phenomena.

When the skull is set into vibration, as by a bone-conduction vibrator or a tuning fork, the bones of the skull become distorted, resulting in distortion of the structures of hearing within the cochlea of the inner ear. This distortion activates certain cells and gives rise to electrochemical activity that is identical to the activity created by an air-conduction signal. This is called **distortional bone conduction**.

While the skull is moving, the chain of tiny bones in the middle ear, owing to its inertia, lags behind so that the third bone, the stapes, moves in and out of an oval-shaped window into the cochlea. Thus, activity is generated within the cochlea as in air-conduction stimulation. This mode of inner-ear stimulation is appropriately called **inertial bone conduction**.

Simultaneously, oscillation of the skull causes vibration of the column of air in the outer-ear canal. Some of these sound waves pass out of the ear, whereas others go further down the canal, vibrating the tympanic membrane and following the same sound route as air conduction. This third mode is called **osseotympanic bone conduction**. Hearing by bone conduction results from an interaction of these three ways of stimulating the cochlea.

For many years the prominent bone behind the ear (the mastoid process) has been the place on the head from which bone-conduction measurements have been made. This was probably chosen (1) because bone-conducted tones are loudest from the mastoid in normal-hearing persons and (2) because of each mastoid process's proximity to the ear being tested. Probably the bone-conducted tone is loudest from behind the ear because the chain of middle ear bones is driven on a direct axis, taking maximum advantage of its hinged action. The notion that placing a vibrator behind the right ear results in stimulation of only the right cochlea is false because vibration of the skull from any location results in approximately equal stimulation of both cochleas (Figure 4.11).

Years ago, Studebaker (1962) demonstrated that the forehead is in many ways superior to the mastoid process for measurement of clinical bone-conduction thresholds. Variations produced by

8. The three ways by which we hear through bone conduction are _____, _____, and _____.

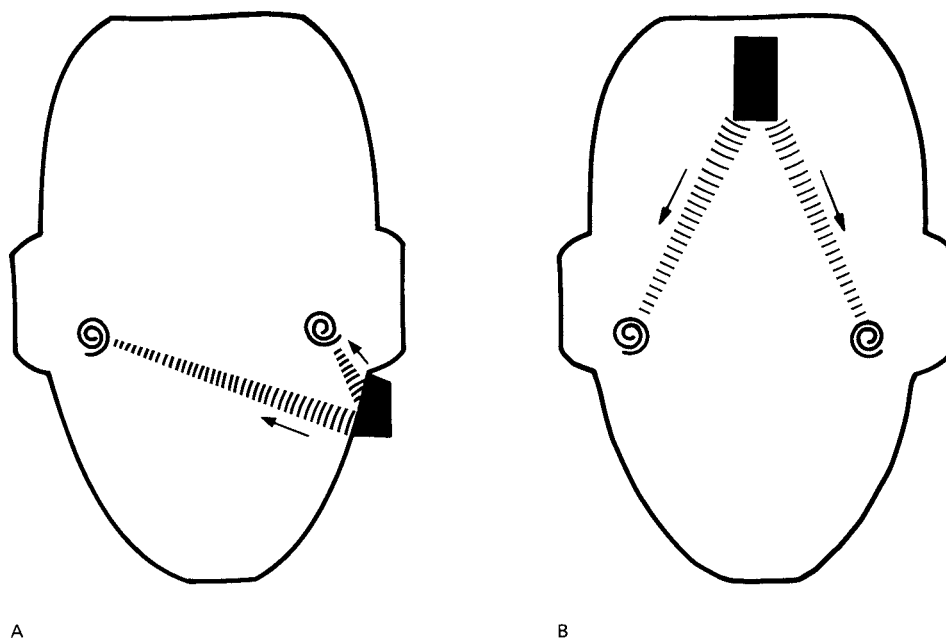


FIGURE 4.11 Vibrations of the skull result in bone-conducted stimulation of both inner ears, whether the vibrator is placed on (A) the mastoid or (B) the forehead.

vibrator-to-skull pressure, artifacts created by abnormalities of the sound-conducting mechanism of the middle ear, test-retest differences, and so on are all of smaller consequence when testing from the forehead than from the mastoid. The greater amount of acoustic energy generated in the outer ear canal when the mastoid is the test site, as compared to the forehead, is further evidence of the advantage of forehead testing (Fagleson & Martin, 1994).

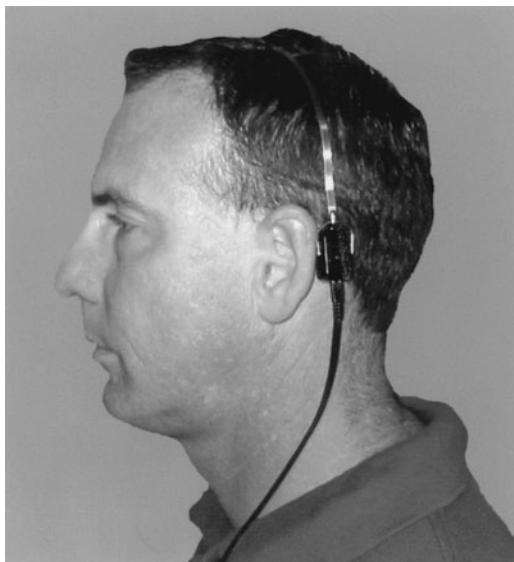
In addition to the theoretical advantages of forehead bone-conduction testing, there are numbers of practical conveniences. The headband used to hold the bone-conduction vibrator is much easier to affix to the head than the mastoid headband. Also, eyeglasses need not be removed when the vibrator is placed on the forehead, which is the case for mastoid placement.

The main disadvantage of testing from the forehead is that about 10 dB greater intensity is required to stimulate normal thresholds, resulting in a decrease of the maximum level at which testing can be carried out. Although bone-conduction testing should sometimes be done from both the forehead and the mastoid, the forehead is recommended here for routine audiometry. Despite negative reports on mastoid test accuracy and other problems that go back many years (e.g., Barany, 1938), a national survey (Martin, Champlin, & Chambers, 1998) shows that the mastoid process continues to be the preferred bone-conduction vibrator site among audiologists. It is hoped that this situation will change.

When the mastoid is the place of measurement, a steel headband crosses the top of the head (Figure 4.12A). If testing is to be done from the forehead, the bone-conduction vibrator should be affixed to the centerline of the skull, just above the eyebrow line. A plastic strap encircles the head, holding the vibrator in place (Figure 4.12B). All interfering hair must be pushed out of the way, and the concave side of the vibrator should be placed against the skull.

9. The most reliable placement for the vibrator when testing by bone conduction is the _____.

For a demonstration of the proper placement of bone-conduction vibrators, see the video titled “Bone-Conduction Receiver Placement” in the Clinical Demonstrations section of the Companion Website.



(A)



(B)

FIGURE 4.12 Bone-conduction vibrator placement on (A) the mastoid process and (B) the forehead.

TABLE 4.2 Occlusion Effect for Bone Conduction Produced When a Supra-Aural Earphone-Cushion Arrangement (TDH-39 earphone in MX/41AR cushion) Is Placed over the Ear during Bone-Conduction Tests

The amounts shown indicate central tendencies and the range of occlusion effects may be considerable (Elpern & Naunton, 1963).

Frequency (Hz)	250	500	1000	2000	4000
Occlusion effect (dB)	30	20	10	0	0

Both ears must be uncovered during routine bone-conduction audiometry. When normal ears and those with sensory/neural impairments are covered by earphones or occluded by other devices, there is an increase in the intensity of sound delivered by a bone-conduction vibrator to the cochlea, which occurs partly because of changes in osseotympanic bone conduction. This phenomenon, called the occlusion effect (OE), occurs at frequencies of 1000 Hz and below. The occlusion effect is rare in patients with conductive hearing losses (e.g., problems in the middle ear) because the increase in sound pressure created by the occlusion is attenuated by the hearing loss. The occlusion effect (Table 4.2) explains the results on the Bing tuning-fork test described in Chapter 2. Research findings confirm previous notions that the occlusion effect is the result of the increase in sound-pressure level in the external ear canal when the outer ear is covered (Fagelson & Martin, 1994; Martin & Fagelson, 1995). Dean and Martin (2000) compared supra-aural earphones to insert earphones with slight and deep insertion and found the occlusion effect to be markedly decreased when the insert phone was deeply inserted, virtually eliminating it at 1000 Hz. This has profound effects when masking for bone conduction, as will be discussed in Chapter 6.



For a demonstration of a pure-tone bone-conduction test, see the video entitled “Bone-Conduction Testing” in the Clinical Demonstrations section of the Companion Website.

Procedure for Bone-Conduction Audiometry

The decision of which ear to test first in mastoid bone-conduction audiometry is unimportant. As a matter of fact, as is illustrated in Figure 4.11, clinicians really cannot be certain which cochlea they are testing. The procedure for actual testing is identical to that for air conduction, although the range of frequencies to be tested and the maximum intensities emitted are more limited for bone conduction than for air conduction.

Bone-conduction thresholds may be recorded in identical fashion to those for air conduction, using the appropriate spaces on the audiometric worksheet. All audiograms should contain a key that tells the reader the symbols used and what they represent. The symbol for forehead (or ear unspecified) bone conduction is a black V when no masking is used. When the nontest ear is masked for forehead bone-conduction testing, a red $\sqcap$ is used as a symbol for the right ear and a blue $\sqcap$ for the left ear. If the mastoid is the test site, a red arrowhead pointing to the reader's left ($\triangleright$) is used for the right ear and a blue arrowhead pointing to the reader's right ($\triangleright$) for the left ear. If the printed page is viewed as the patient's face looking at the reader, the symbols for right and left are logical. When masking is used in the nontest ear, the symbols are changed to square brackets, $\sqcap$ in red for the right ear and $\sqcap$ in blue for the left ear. Some audiologists prefer to connect the bone-conduction symbols on the audiogram with a dashed red line for the right ear and a dashed blue line for the left ear. Others prefer not to connect the symbols

at all. The latter is the preference in this book. At times, a patient may give no response at the maximum bone-conduction limits of the audiometer. When this occurs, the appropriate symbol should be placed under the test frequency where that line intersects the maximum testable level. An arrow pointing down indicates no response at that level. Figure 4.10 shows the recording of results and plotting of an audiogram for a hypothetical normal-hearing individual.

The Audiometric Weber Test

The Weber test, described in Chapter 2, can be performed by using the bone-conduction vibrator of an audiometer. The vibrator is placed on the midline of the skull, just as for forehead bone-conduction testing, and the level of the tone is raised until it is above the patient's hearing threshold. Tones of different frequencies are then presented, and patients are asked to state whether they hear them in the left ear, in the right ear, or in the midline. Midline sensations are sometimes described as being heard in both ears or as unlocalized.

It is expected that, during the Weber test, tones will be referred to the poorer-hearing ear in a conductive loss, to the better ear in a sensory/neural loss, and to the midline in symmetrical losses or normal hearing. It has been suggested that the **audiometric Weber test** be used to determine which ear to mask during bone-conduction testing. This notion is not encouraged here, as there are several reasons why the Weber may be misleading. Weber results help in the confirmation or denial of results obtained from standard pure-tone audiometry, and the probable results on this test are illustrated in all of the audiograms in this book.

Audiogram Interpretation

Whether the audiometric results have been recorded as numbers or plotted on a graph, they are interpreted in the same way. Results must be looked at for each frequency in terms of (1) the amount of hearing loss by air conduction (the hearing level), (2) the amount of hearing loss by bone conduction, and (3) the relationship between air-conduction and bone-conduction thresholds.

A wide variety of pure-tone configurations may be seen among patients and within various pathologies. While some configurations may be suggestive of a given pathology, it is not always possible to identify pathology by audiometric configuration alone. Some distinct gender effects have been noted in audiometric configuration with a wider variation in configuration and a greater preponderance of more steeply sloping audiograms reported for men (Ciletti & Flamme, 2009).

The effects of different hearing-loss configurations on the perceived clarity of speech may be heard on the Companion Website under "Simulated Hearing Loss" in the Learning Supplements section.



The audiometric results depicted in Figure 4.13 illustrate a **conductive hearing loss** in both ears. There is approximately equal loss of sensitivity at each frequency by air conduction. Measurements obtained by bone conduction show normal hearing at all frequencies. Therefore, the air-conduction results show the loss of sensitivity (about 35 dB); the bone-conduction results show the amount of sensory/neural impairment (none); and

10. The conductive component of a hearing loss can be determined by the _____.

SPEECH AND HEARING CENTER
The University of Texas at Austin 78712
AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐	RIGHT										LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000		
Masking Type WB ☐ NB ☐	35	30	40	40	35	35	40	45	45	35	30	40	35	35	45	40	45	50		
EM Level in Opp. Ear																				

BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT								FOREHEAD								LEFT							
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000						
Masking Type WB ☐ NB ☒	0*	-5*	5*	0*	5*	10*	0	-5	5	0	5	10	0*	-5*	5*	0*	5*	10*						
EM Level in Opp. Ear	35	30	40	35	45	40							35	30	40	35	35	40						

		WEBER				
		2 Freq	3 Freq	Variable		
Pure Tone Average		33	35	38	M	M

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☐	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
			List HL	%			List HL	%
EM Level in Opp. Ear								

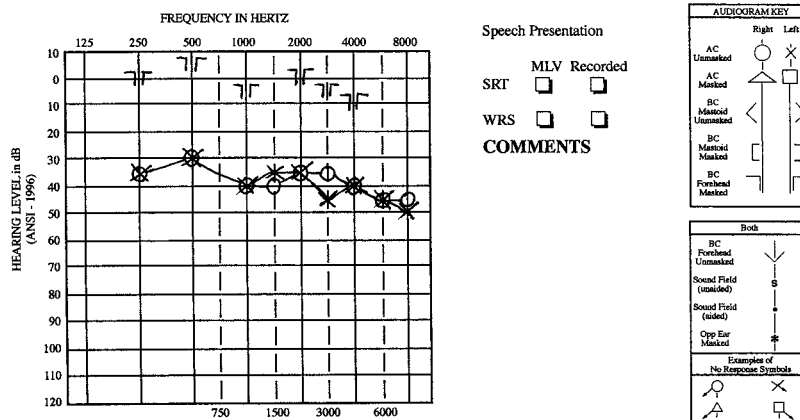


FIGURE 4.13 Audiogram illustrating a conductive hearing loss in both ears. The three-frequency pure-tone averages are 35 dB HL in each ear. Bone-conduction thresholds were obtained from the forehead, first without masking and then with masking, and average 0 dB HL. There are air-bone gaps of about 35 dB (conductive component) in both ears. An asterisk is used to denote that nontest-ear masking was used. Bone-conduction results obtained from the forehead with the left ear masked are assumed to come from the right cochlea, and bone-conduction results obtained from the forehead with the right ear masked are assumed to come from the left cochlea. No lateralization is seen on the Weber test at any frequency. The determination of need for and correct amounts of masking are covered in detail in Chapter 6.

the difference between the air- and bone-conduction thresholds, which is called the **air-bone gap (ABG)**, shows the amount of conductive involvement (35 dB).

Figure 4.14 shows an audiogram similar to that in Figure 4.13; however, Figure 4.14 illustrates a bilateral **sensory/neural hearing loss**. Again, the air-conduction results show the total amount of loss (35 dB), the bone-conduction results show the amount of sensory/neural impairment (35 dB), and the air-bone gap (0 dB) shows no conductive involvement at all.

SPEECH AND HEARING CENTER
The University of Texas at Austin 78712
AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐	RIGHT										LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000		
Masking Type WB ☐ NB ☐	25	30	35	40	40	50	55	65	65	20	25	30	40	50	60	65	65	70		
EM Level in Opp. Ear																				

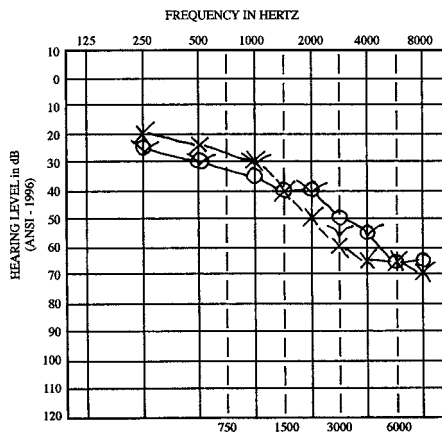
BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT						FOREHEAD						LEFT					
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type WB ☐ NB ☐							25	30	30	40	55	55						
EM Level in Opp. Ear																		

Pure Tone Average	2 Freq	3 Freq	Variable	WEBER							2 Freq	3 Freq	Variable
	33	35	43	M	M	M	M	M	M	28	35	48	

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☐	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
			List HL	%			List HL	%
EM Level in Opp. Ear								



Speech Presentation

MLV Recorded ☐

SRT ☐

WRS ☐

COMMENTS

AUDIOGRAM KEY	
Right	Left
AC Unmasked	AC Unmasked
AC Masked	AC Masked
BC Mastoid Unmasked	BC Mastoid Unmasked
BC Mastoid Masked	BC Mastoid Masked
BC Forehead Unmasked	BC Forehead Masked

Both	
BC Forehead Unmasked	BC Forehead Masked
Sound Field (unaided)	Sound Field (aided)
Opp Ear Masked	Opp Ear Masked
Examples of No Response Symbols	

FIGURE 4.14 Audiogram illustrating sensory/neural hearing loss in both ears. The air-conduction thresholds average 35 dB HL and the bone-conduction thresholds (obtained from the forehead), about the same (33 dB HL). Tones are heard in the midline at all frequencies on the Weber test.

The results shown in Figure 4.15 suggest a typical **mixed hearing loss** in both ears. In this case the total loss of sensitivity is much greater than in the previous two illustrations, as shown by the air-conduction thresholds (60 dB). Bone-conduction results show that there is some sensory/neural involvement (35 dB). The air-bone gap shows a 25 dB conductive component.

Sometimes high-frequency tones radiate from the bone-conduction vibrator when near-maximum hearing levels are presented by bone conduction. If the patient hears these signals by air conduction, the false impression of an air-bone gap may be made. Since this only occurs at 3000 and 4000 Hz, it is unlikely that a misdiagnosis of conductive hearing loss would be made. This small inaccuracy can be ameliorated by testing bone conduction from the forehead since

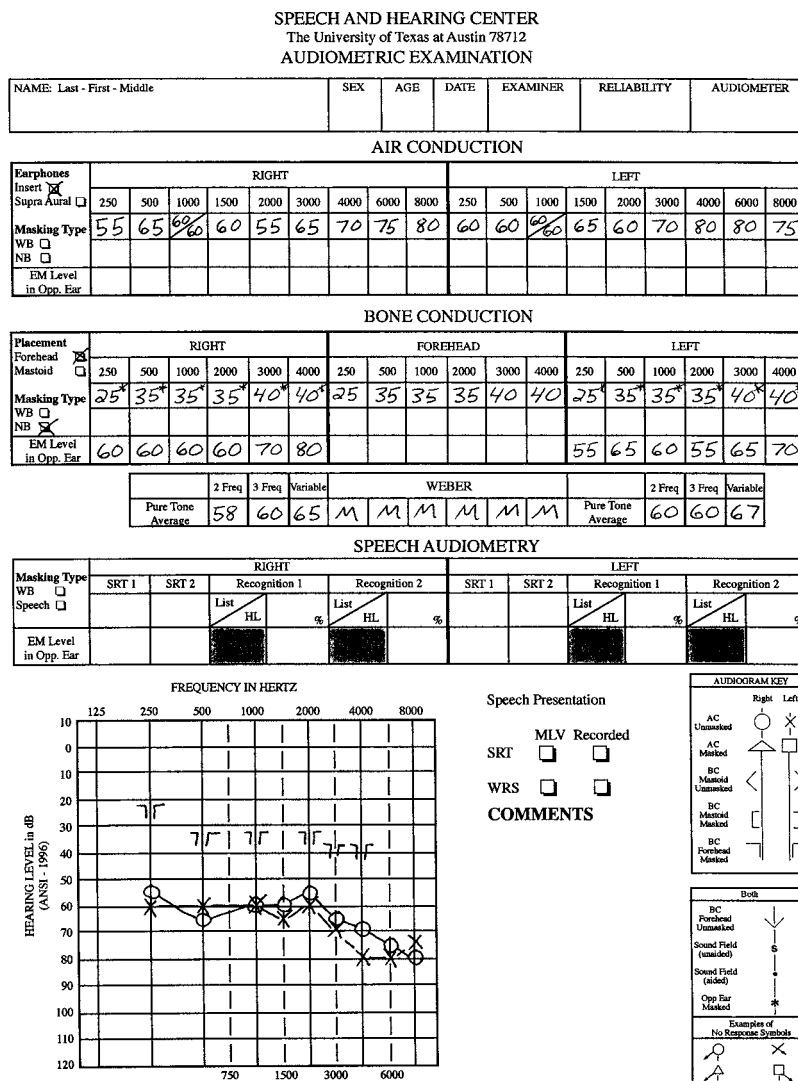


FIGURE 4.15 Audiogram illustrating a mixed hearing loss in both ears. The air-conduction thresholds average about 60 dB HL (total hearing loss), whereas the bone-conduction thresholds average 35 dB HL (sensory/neural component). Masking, as will be explained in Chapter 6, was required for all frequencies for bone conduction. There is an air-bone gap of about 25 dB (conductive component). Tones on the Weber test do not lateralize.

Harkrider and Martin (1998) found less acoustic radiation in the high frequencies from the forehead than from the ipsilateral mastoid.

Interpretation of the air-bone relationships can be stated as a formula that reads as follows: The air-conduction (AC) threshold is equal to the bone-conduction (BC) threshold plus the air-bone gap (ABG), which is determined at each audiometric frequency. With this formula, the four audiometric examples just cited would read

Formula:	AC = BC + ABG
Figure 4.10:	5 = 5 + 0 (normal)
Figure 4.13:	35 = 0 + 35 (conductive loss)
Figure 4.14:	35 = 35 + 0 (sensory/neural loss)
Figure 4.15:	60 = 35 + 25 (mixed loss)

Air-Bone Relationships

Figure 2.2 suggests that (1) hearing by bone conduction is the same as by air conduction in individuals with normal hearing and in patients with sensory/neural impairment (no air-bone gap) and (2) hearing by air conduction is poorer than by bone conduction in patients with conductive or mixed hearing losses (some degree of air-bone gap), but (3) hearing by bone conduction poorer than by air conduction should not occur because both routes ultimately measure the integrity of the sensory/neural structures. It has been shown that, although assumptions 1 and 2 are correct, 3 may be false. There are several reasons why bone-conduction thresholds may be slightly poorer than air-conduction thresholds, even when properly calibrated audiometers are used. Some of these arise from changes in the inertial and osseotympanic bone-conduction modes produced by abnormal conditions of the outer or middle ears. More than four decades ago Studebaker (1967) demonstrated that slight variations between air-conduction and bone-conduction thresholds are bound to occur based purely on normal statistical variability. Slight differences between air- and bone-conduction thresholds are to be anticipated (Barry, 1994) and are built into the ANSI (1992) standard for bone conduction. Because no diagnostic significance can be attached to air-conduction results being better than those obtained by bone conduction, the insecure clinician may be tempted to alter the bone-conduction results to conform to the usual expectations. Such temptations should be resisted because (in addition to any ethical considerations) they simply propagate the myth that air-conduction thresholds can never be lower than bone-conduction thresholds.

11. In mixed hearing losses the sensory/neural component is shown by the _____.

Tactile Responses to Pure-Tone Stimuli

At times, when severe losses of hearing occur, it is not possible to know for certain whether responses obtained at the highest limits of the audiometer are auditory or tactile. Nober (1970) has shown that some patients feel the vibrations of the bone-conduction vibrator and respond when intense tones are presented, causing the examiner to believe the patient has heard them. In such cases a severe sensory/neural hearing loss may appear on the audiogram to be a mixed hearing loss, possibly resulting in unjustified surgery in an attempt to alleviate the conductive component. Martin and Wittich (1966) found that some children with severe hearing impairments often could not differentiate tactile from auditory sensations. Nober found that it is possible for patients to respond to tactile stimuli to both air- and bone-conducted tones, primarily in the low frequencies, when the levels are near the maximum outputs of the audiometer. When audiograms show severe mixed hearing losses, the validity of the test should be questioned.

See Case Studies on the Companion Website for this book.



Dean and Martin (1997) describe a procedure for ascertaining whether a severe mixed hearing loss has a true conductive component or if the ABG is caused by tactile stimulation. It is based on the fact that bone-conduction auditory thresholds are higher on the forehead than the mastoid, but tactile thresholds are lower on the forehead than the mastoid, at least for the low frequencies. The procedure works as follows (assuming that original bone-conduction

12. Severe sensory/neural hearing losses may be misdiagnosed as mixed losses when the bone-conduction responses are _____.

results were obtained from the forehead): Move the vibrator to the mastoid and retest at 500 Hz. If the threshold gets lower (better), the original response was auditory. If the threshold gets higher, the original response was tactile.

If the mastoid was the original test position and a **tactile response** is suspected, move the vibrator to the forehead and retest at 500 Hz. If the threshold appears to get lower, the original response was tactile. If the threshold gets higher, the original response was auditory.

Cross Hearing

When there are differences in hearing sensitivity between the two ears, there may be a risk that sounds that are presented to one ear (the test ear) may actually be heard in the opposite (nontest) ear. It is important for clinicians to be alert to these possibilities and to deal with them effectively. These matters are addressed in detail in the chapter on masking (Chapter 6).

Automatic Audiometry

Audiometers have been devised that allow patients to track their own auditory thresholds while they are automatically recorded in the form of a graph on a special form. Automatic audiometers can test discrete frequencies or may use a variable oscillator with a range from 100 to 10,000 Hz. The tones may be either automatically pulsed (200 msec on/200 msec off), or presented continuously. The tone gradually increases in intensity beginning at an inaudible level. When patients hear the tone, they press a hand switch, which reverses the attenuator, causing the signal to get weaker. When the tone becomes inaudible, the hand switch is released and the tone is allowed to increase in intensity again. Frequency can be either set or can continue to increase whether the intensity is increasing or decreasing. This procedure is called **Békésy audiometry**.² Upon completion of the test, an audiogram has been drawn that represents the patients' thresholds for discrete frequencies or over a continuous frequency range (Békésy, 1947).

Although popular for a time as a test for auditory site of lesion, the clinical use of automatic audiometry has faded from prominence. While there is value in testing between the normal discrete audiometric frequencies, the limited use of automatic audiometry is largely found in industrial settings.

Computerized Audiometry

Computers may be programmed to control all aspects of administering pure-tone air- and bone-conduction stimuli, recognize the need for masking, determine the appropriate level of masking, regulate the presentation of the masker to the nontest ear, analyze the subject's responses in terms of threshold-determination criteria, and present the obtained threshold values in an audiogram format at the conclusion of the test. **Computerized audiometry** is performed on a device that is

microprocessor controlled, and the audiometric data may be “dumped” into a computer file for later retrieval.

Possibly due to economic considerations, several companies have been formed that specialize in hearing testing performed by nonaudiologists, sometimes called para-audiologists or oto-techs. These individuals, many of whom have no academic training in hearing and its disorders, are trained to use automated devices that are programmed to complete pure-tone audiometry, and speech audiometry (Chapter 5), as well as immittance measures (Chapter 7), in a matter of 20 minutes. The claims by these firms are that the results are reliable, but this has not been empirically verified. Certainly automated audiometry cannot be used reliably with noncooperative patients (Chapter 13) or with young children or the very elderly who may need more personalized modifications in test procedure and speed to accommodate the test situation.

Presumably, in these computerized hearing settings physicians carry out the counseling and follow-up. This leaves the patients without the special training of clinical audiologists in the areas of counseling, therapy, and amplification systems. Despite its sophistication, the computer has not replaced, nor is it likely to replace, the clinical audiologist in the performance of auditory tests outside of its possible use with test-cooperative patients. The fact that computers can make step-by-step decisions in testing helps to prove that many hearing tests can be carried out logically and scientifically.

EVOLVING CASE STUDIES

You were introduced to four theoretical case studies in Chapter 2. The next step is to predict, based on your reading of Chapter 4, what the pure-tone audiometric results would be for each of these cases. Sketch an audiogram for each case and compare your results to the discussion below, bearing in mind that there will naturally be some differences.

Case Study 1: Conductive Hearing Loss

Audiometric findings for this patient should be similar to what is observed in Figure 4.13. Note that there is a mild-to-moderate hearing loss by air conduction for both ears (the pure-tone averages are 35 dB HL) but that the bone-conduction thresholds are normal, indicating normal sensory/neural sensitivity. The resultant air-bone gaps show the degree of conductive involvement. These results do not indicate the etiology (cause) of the hearing loss or the part of the auditory system that is involved, but the tests described in later chapters will assist in this regard. The history of ear infections suggests this as the etiology but may be misleading.

Case Study 2: Sensory/Neural Hearing Loss

Compare the audiogram you have drawn to Figure 4.14. Results should be similar but surely will not be identical. You should have shown a moderate loss, in this case approximately 45 dB based upon the variable pure-tone average (poorest three thresholds for 500, 1000, 2000, and 4000 Hz), but the air-conduction and bone-conduction thresholds should be about the same. The lack of an air-bone gap indicates that the loss is entirely sensory/neural. The case history points to aging as the etiology but further tests, as described in later chapters, can help to determine the site of the pathology.

Case Study 3: Erroneous Hearing Loss

There is no audiogram in Chapter 4 to illustrate this case since your patient appears to be pretending to have no hearing in his left ear. What you may have drawn should closely resemble Figure 13.2A. He is reporting normal hearing in his right ear and gives no response by either air conduction or bone conduction at the highest intensities in his left ear. This is actually impossible because at some intensity (possibly as low as 40 dB HL for supra-aural earphones and 70 dB HL for insert earphones) the sound would have lateralized (crossed the skull) and been heard in the right ear. This total lack of response is a clear indication that the hearing loss in the left ear cannot be of the degree claimed, but based on the present information it cannot be learned just how much loss exists in the left ear, if any. Chapter 5 will allow for more insights about this case, and Chapter 13 will describe tests that are specific to erroneous hearing loss.

Case Study 4: Pediatric Patient

The test procedures described in Chapter 4 are designed for adults and older children, or young children who are particularly cooperative. There are some youngsters who can take adult-level tests that have been modified by an audiologist who provides significant social reward for accurate responses. Unfortunately, this child is not in this category and so you are referred to Chapter 8 to learn about procedures specifically designed for pediatric patients.

Summary

For pure-tone hearing tests to be performed satisfactorily, control is needed over such factors as background noise levels, equipment calibration, patient comprehension, and clinician expertise. The audiologist must be able to judge when responses are accurate, and to predict when a sound may have actually been heard in the ear not being tested. When this cross hearing occurs, proper masking procedures must be instituted to overcome this problem as discussed in Chapter 6. Although at times the performance of pure-tone hearing tests is carried out as an art, it should, in most cases, be approached in a scientific manner using rigid controls.

REVIEW TABLE 4.1 Summary of Pure-Tone Hearing Tests
(Minimal interaural attenuation is considered to be 40 dB for supra-aural earphones and 70 dB for insert earphones.)

<i>Test</i>	<i>Air Conduction (AC)</i>	<i>Bone Conduction (BC)</i>
Purpose	Hearing sensitivity for pure tones	Sensory/neural sensitivity for pure tones
Interpretation	AC audiogram shows amount of hearing loss at each frequency	BC audiogram shows degree of sensory/neural loss at each frequency Air-bone gap shows amount of conductive impairment at each frequency

REVIEW TABLE 4.2 Possible Findings for Air Conduction (AC) and Bone Conduction (BC)

<i>Finding</i>	<i>Possibilities</i>	<i>Eliminate</i>
Normal AC	Normal hearing	Conductive loss Sensory/neural loss Mixed loss
Normal BC	Normal hearing Conductive loss	Sensory/neural loss Mixed loss
Impaired AC	Conductive loss Sensory/neural loss Mixed loss	Normal hearing
Impaired BC	Sensory/neural loss Mixed loss	Normal hearing Conductive loss

Study Questions

1. Sketch an audiogram from memory. What is the proportional relationship between hearing level and the octave scale? Why?
2. Draw audiograms from memory illustrating normal hearing, conductive hearing loss, sensory/neural hearing loss, and mixed hearing loss. What would the results for these hypothetical patients be on the tuning-fork tests described in Chapter 2?
3. Name the parts of a pure-tone audiometer.
4. How would you calibrate an audiometer for air conduction and bone conduction, both with and without electroacoustic equipment?
5. What are the advantages and disadvantages of insert receivers for air-conduction testing?
6. List the advantages and disadvantages of testing bone conduction from the forehead and the mastoid.
7. Describe the audiometric Weber test. What possible hearing losses might yield a lateralization to the right ear? When might you employ this test?

Suggested Readings

Bankaitis, A. U., & Kemp, R. J. (2003). *Infection control in the audiology clinic*. Boulder, CO: Auban.

Schlauch, R. S., & Nelson, P. (2009). Puretone evaluation. In J. Katz, L. Medwetsky, R. Burkhard, & L. Hood (Eds.), *Handbook of*

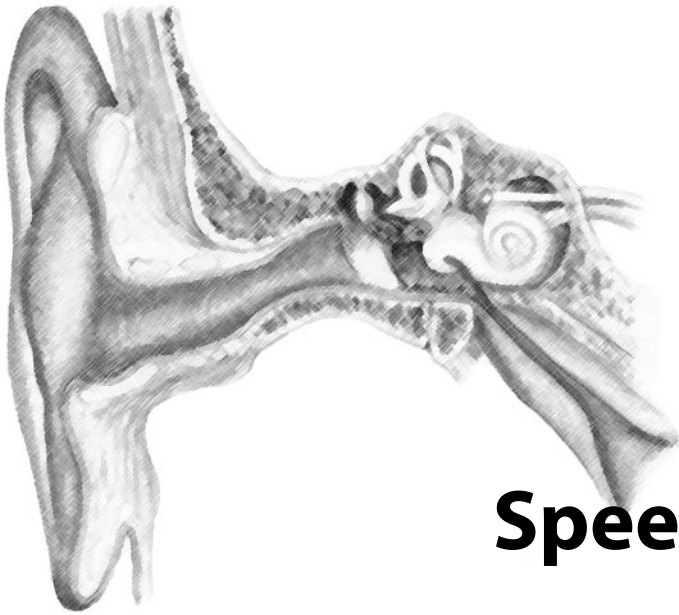
clinical audiology (pp. 30–49). Baltimore: Lippincott Williams & Wilkins.

Endnotes

1. The term “audiometer” was first coined by an English physician, Benjamin Richardson, in 1879. It was not until 1919 that the first clinically useful audiometer, the Pitch Range Audiometer, was developed by Lee Dean and Cordia Bunch.
2. This test was suggested by Dr. Georg von Békésy, the Hungarian-born physicist (1899–1976) who won the Nobel Prize in 1961 for his contributions to the understanding of the human cochlea.

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Speech Audiometry

THE HEARING IMPAIRMENT INFERRED from a pure-tone audiogram cannot depict, beyond the grossest generalizations, the degree of disability in speech communication caused by a hearing loss. Because difficulties in hearing and understanding speech evoke the greatest complaints from patients with hearing impairments, it is logical that tests of hearing function should be performed with speech stimuli. Modern diagnostic audiometers include circuitry for measuring various aspects of receptive speech communication (Figures 3.23 and 3.24, page 59). Using speech audiometry, audiologists set out to answer questions regarding patients' degree of hearing loss for speech; the levels required for their most comfortable and uncomfortable loudness levels; their range of comfortable loudness; and, perhaps most importantly, their ability to recognize and discriminate the sounds of speech. Speech-language pathologists use reported findings of speech audiometric results in both therapy planning and client and family counseling.

LEARNING OBJECTIVES

Chapter 4 introduced the concept of pure-tone audiometry and described its administration and interpretation. This chapter acquaints the reader with speech audiometry and some of its ramifications. The new vocabulary in this chapter, and reviewed in the glossary, is indispensable for understanding the concepts that follow in this book. Upon completion of this chapter the beginning student should

- Have a fundamental knowledge of the measures obtained with speech audiometry such as threshold for speech, most comfortable and uncomfortable loudness levels, and word-recognition ability.

- Be able to interpret speech audiometric results, relate them to pure-tone threshold tests, and, after some supervised practice with an audiometer, actually perform the tests described in this chapter.
- Understand the implications of speech audiometric tests to speech-language therapy planning and goal setting.

The Diagnostic Audiometer

In the early days of speech audiometry, separate speech audiometers were used to perform the measurements to be described in this chapter. Modern devices have these circuits incorporated, along with circuitry for pure tones, into a single unit. Diagnostic audiometers are either accompanied by or have auxiliary inputs for testing with microphones, cassette tape decks, or compact disks. A volume units (VU) meter is used to visually monitor the intensity of the input source.

Diagnostic audiometers contain a circuit for masking the nontest ear or for mixing a noise with a speech signal in the same ear. Tests can usually be carried out in either ear (**monaural**) or in both ears simultaneously (**binaural**). Hearing level controls that usually have a range of 120 dB (from -10 to 110 dB HL, according to ANSI-2004 values) are provided. Auxiliary amplifiers are available so that speech can be channeled to one or more loudspeakers for testing in the sound field. A talkback system is available for communication between separate rooms that hold the clinician and the patient.

Test Environment

Most speech audiometry is carried out with the patient isolated from the examiner in either one- or two-room sound-treated suites (see Figure 4.3 on page 76 for an example). This is mandatory when

monitored live-voice (MLV) testing is used, because if examiners and patients are in the same room there is no way to ensure that the patients are responding to sounds channeled to them through the audiometer rather than directly through the air in the room. If prerecorded materials are used, same-room operation is possible, but this is probably an unusual procedure. Problems of ambient noise levels are very much the same for speech audiometry as for pure-tone tests as discussed in Chapter 4.

There are significant advantages to using recorded materials. Primarily, they provide a consistency of presentation that is independent of the expertise of the clinician. Most audiologists appear to prefer monitored live-voice testing, because they feel it provides more flexibility in delivering the stimuli and often takes less time. With the advent of the CD some of these objections have been overcome, and, for the most part, the CD should be used instead of live-voice testing.

The Patient's Role in Speech Audiometry

To use speech audiometry, patients must know and understand reasonably well the words with which they are to be tested. Depending on the type of test, a response must be obtainable in the form of an oral reply, a written reply, or the identification of a picture or object.

1. prerecorded materials, monitored live-voice, prerecorded materials

1. Of the two methods for presenting speech audiometry materials, _____ and _____, the recommended procedure is _____.

Although spoken responses are more necessary in some speech tests than in others, they have certain advantages and disadvantages. One advantage is in the speed with which answers can be scored. Also, a certain amount of rapport is maintained through the verbal interplay between the patient and the audiologist. One serious drawback is the possible misinterpretation of the patient's response. Many people seen for hearing evaluation have speech and/or language difficulties that make their responses difficult to understand. For example, Nelson, Henion, and Martin (2000) found that non-native speakers of Spanish were less accurate at scoring Spanish word-recognition tests than were native speakers. Also, discrepancies occur in the scoring of some speech tests when verbal responses are obtained because audiologists tend to score some incorrectly spoken responses as correct.

In addition, for reasons that have never become completely clear, the talkback systems on many audiometers are often of poor quality, sounding very little better than inexpensive intercom systems. This creates an additional problem in interpreting responses.

Written responses lend themselves only to tests that can be scored upon completion. When responses require an instantaneous value judgment by the audiologist, written responses are undesirable. When used, however, written responses do eliminate errors caused by difficulties in discriminating the patient's speech; they also provide a permanent record of the kinds of errors made. Having patients write down or otherwise mark responses may slow down some test procedures and necessitate time at the end of the test for scoring. Difficulties with handwriting and spelling provide additional, although not insurmountable, problems.

The use of pictures or objects is generally reserved for small children, who otherwise cannot or will not participate in a test. Adults with special problems are sometimes tested by this method, in which the patient is instructed to point to a picture or object that matches a stimulus word.

2. False _____
responses are unlikely
during speech
audiometry.

False responses may occur in speech audiometry, as well as in pure-tone audiometry. False positive responses are theoretically impossible, because patients cannot correctly repeat words or sentences that have been presented to them below their thresholds, unless, through the carelessness of the examiner, they have been allowed some visual cues and have actually lip-read the stimulus words. False negative responses, however, do occur. The audiologist must try to make certain that the patient completely understands the task and will respond in the appropriate manner whenever possible.

No matter how thorough the attempt to instruct patients, it is impossible to gain total control over the internal response criteria each individual brings to the test. It has been suspected, for example, that aging might affect the relative strictness of these criteria. Jerger, Johnson, and Jerger (1988), however, demonstrated that aging alone does not appear to affect the criteria that listeners use in giving responses to speech stimuli. All the alert clinician can do is to instruct patients carefully and be aware of overt signs of deviation from expected behaviors.

The Clinician's Role in Speech Audiometry

First and foremost in speech audiometry, through whatever means necessary, the audiologist must convey to patients what is expected of them during the session. A combination of written and verbal instructions is usually successful with adults and older children, whereas gestures and pantomime may be required for small children and certain adults. At times, the instructions are given to patients through their hearing aids or, if this is not feasible, through a portable amplifier or the microphone circuit of the audiometer.

It is just as important that the patient not observe the examiner's face during speech audiometry as it is during pure-tone audiometry, and even more so if monitored live-voice testing is used. The diagram in Figure 4.5 (page 79) shows a desirable arrangement.

Speech-Threshold Testing

The logic of pure-tone threshold testing carries over to speech audiometry. If a patient's thresholds for speech can be obtained, they can be compared to an average normal-hearing individual's thresholds to determine the patient's degree of hearing loss for speech. Speech thresholds may be of two kinds: the **speech-detection threshold (SDT)** and the **speech-recognition threshold (SRT)**.

The terminology used in speech audiometry has been inconsistent. Konkle and Rintelmann (1983) feel that the word *speech* itself may be too general and that the specific speech stimuli in any test should always be specified. Likewise, they are concerned with the conventional term *speech-reception threshold*, since the listener is asked to recognize, rather than receive, the words used in the test. In the "Guidelines for Determining Threshold Level for Speech," ASHA (1988) also recommends the term *speech-recognition threshold* as preferable to the earlier term *speech-reception threshold*.

Speech-Detection Threshold

The speech-detection threshold (SDT) may be defined as the lowest level, in decibels, at which a subject can barely detect the presence of speech and identify it as speech. The SDT is sometimes called the speech-awareness threshold (SAT). This does not imply that the speech is in any way understood—rather, merely that its presence is detected. One way of measuring the SDT is to present to the patient, through the desired output transducer, some continuous discourse. The level of the speech is raised and lowered in intensity until the patient indicates that he or she can barely detect the speech and recognize it as speech.

Sentences are preferable to isolated words or phrases for finding the SDT. The sentences should be presented rapidly and monotonously so that there are few peaks above and below zero on the VU meter, or series of light-emitting diodes designed to control the input level of the speech signal. The materials should be relatively uninteresting, hence the term **cold running speech**.

Whether the right ear or the left ear is tested first is an arbitrary decision. Sometimes tests of SDT are run binaurally, or through the sound-field speakers, either with or without hearing aids. Patients may respond verbally, with hand or finger signals, or with a push-button, indicating the lowest level, in dB HL, at which they can barely detect speech.

Speech-Recognition Threshold (SRT)

The speech-recognition threshold (SRT) may be defined as the lowest hearing level at which speech can barely be understood. Most audiologists agree that the speech should be so soft that about half of it can be recognized. For a number of reasons, the SRT has become more popular with audiologists than the SDT and is thus the preferred speech-threshold test. In this book very little attention is paid to the SDT, although it has some clinical usefulness. SRTs have been measured with a variety of speech materials using both continuous discourse, as in measurement of the SDT, and isolated words.

Today most SRTs are obtained with the use of **spondaic words**, often called *spondees*. A spondee is a word with two syllables, both pronounced with equal stress and effort. Although spondees do not occur naturally in spoken English, it is possible, by altering stress slightly, to force such common words as baseball, hot dog, and toothbrush to conform to the spondaic configuration. Whether the spondees are spoken into the microphone or introduced by tape or disk, both syllables of the word should peak at zero VU. Although it takes practice for the student to accomplish this equal peaking on the VU meter, most people can acquire the knack relatively quickly.

When a prerecorded list of spondaic words is to be used, it is common to find a calibration tone recorded on a special band. The calibration signal is played long enough so that the gain control for the VU meter can be adjusted with the needle at zero VU. On some prerecorded spondee lists, a **carrier phrase** precedes each word, for example, "Say the word . . .," followed by the stimulus word. Although some clinicians prefer the use of a carrier phrase, many do not. No real advantage of using a carrier phrase with spondaic words has been proved.

3. Spondees are words that have _____ syllables with equal stress.

4. The two most common tests used in measuring thresholds for speech are _____ and _____.

An alphabetized list of spondees may be found under "Forms" in the Professional Resources section of the Companion Website for this book.



SRT Testing with Cold Running Speech

When connected speech is used to measure the SRT, patients are instructed to indicate the level at which the speech is so soft that they can barely follow about half of what is being said. Sometimes this involves using a verbal or hand signal. The level of the speech may be raised and lowered, usually in steps of 5 dB. Several measurements should be taken to ensure accuracy.

5. Connected discourse that is rapid and unemotional is sometimes called _____.

SRT Testing with Spondaic Words

The SRT is usually defined as the lowest hearing level at which 50% of a list of spondaic words is correctly identified. This definition appears incomplete, however, because it does not specify how many words are presented at threshold before the 50% criterion is invoked. Also, many methods used for SRT measurement in the past were rather vague, suggesting that the level should be raised and lowered but not giving a precise methodology.

Martin and Stauffer (1975) recommended testing for the SRT in 5 dB steps, rather than the previous traditional 2 dB steps, which greatly increased test speed without sacrificing test accuracy. Additionally, if the SRT is to serve as an independent measurement of hearing and a check of the reliability of pure-tone thresholds, it should be accomplished without knowledge of the pure-tone thresholds with which it is compared. To attain this goal, Martin and Dowdy (1986) recommend a procedure based on previously recommended outlined steps (Tillman and Olsen, 1973) that is summarized as follows:

1. Set the start level at 30 dB HL. Present one spondee. If a correct response is obtained, this suggests that the word is above the patient's SRT.
2. If no correct response is obtained, raise the presentation level to 50 dB HL. Present one spondee. If there is no correct response, raise the intensity in 10 dB steps, presenting one

3. two; 4. speech-recognition threshold, speech-detection (or awareness) threshold; 5. cold running speech

spondee at each increment. Stop at the level at which either a correct response is obtained or the limit of the equipment is reached.

3. After a correct response is obtained, lower the intensity 10 dB and present one spondee.
4. When an incorrect response is given, raise the level 5 dB and present one spondee. If a correct response is given, lower the intensity 10 dB. If an incorrect response is given, continue raising the intensity in 5 dB steps until a correct response is obtained.
5. From this point on the intensity is increased in 5 dB steps and decreased in 10 dB steps, with one spondee presented at each level until three correct responses have been obtained at a given level.
6. Threshold is defined as the lowest level at which *at least* 50% of the responses are correct, with a minimum of at least three correct responses at that intensity.

6. Popular stimuli used for measuring SRT are _____.

The ASHA (1988) method for determining SRT provides recommendations to ensure patient familiarity with the test vocabulary prior to testing. This goal can be accomplished by allowing the patient to listen to the words as presented through the audiometer and is important regardless of the method employed to measure SRT. Words that present any difficulty should be eliminated from the list. While the ASHA recommendation to familiarize patients with test stimuli is important, the actual ASHA recommended test methods (ASHA, 1978, 1988) have never enjoyed full acceptance (Martin, Champlin, & Chambers, 1998) possibly due to several procedural limitations.

To ensure familiarity with the test it is advisable, whenever possible, to give the patient a list of the words before the test begins, together with printed instructions for the entire test procedure. Although written instructions may serve as an adjunct, they should not routinely replace spoken directions for taking a test. Proper instructions are of great importance in test results. One usable set of instructions follows:

The purpose of this test is to determine the faintest level at which you can hear and repeat some words. Each word you hear will have two syllables, like *hot dog* or *baseball*, and will be selected from the list of words that you have been given. Each time you hear a word, just repeat it. Repeat the words even if they sound very soft. You may have to guess, but repeat each word if you have any idea what it is. Are there any questions?



Hearing test instructions are available in the Professional Resources section on the Companion Website.

Based on investigation with normal-hearing subjects, Burke and Nerbonne (1978) suggest that the slight improvement observed when normal-hearing subjects guess at the correct response should be controlled during SRT tests by asking the patient not to guess. Because no data have surfaced that reveal the effects of guessing on patients with actual hearing losses, the practice will probably continue to encourage guessing to increase attentiveness to the test stimuli.

One reason for the selection of spondaic words for measuring SRT is that they are relatively easy to discriminate and often can be guessed with a high degree of accuracy. Once the threshold for spondees has been reached (50% response criterion), it does not take much of an increase in intensity before all the words can be identified correctly. This is illustrated by the curve in Figure 5.1, which shows the enhanced intelligibility of spondees as a function of increased intensity.

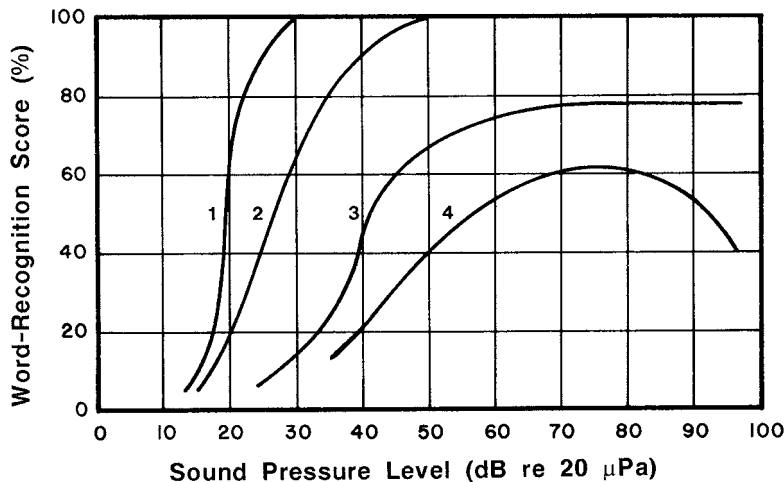


FIGURE 5.1 Theoretical performance-intensity (PI) functions for spondaic and PB words. (1) Spondaic words. Note that at about 5 dB above the 50% correct point, almost all of the words are intelligible. This shows an increase in recognition ability of approximately 10% per decibel for scores between 20% and 80%. (2) PB word lists. Note the more gradual slope for PB words than for spondees. The increase in intelligibility for the W-22 word lists averages about 2.5% per decibel. The normal increase in word-recognition scores with increased intensity is to a maximum of approximately 100% (suggesting normal hearing or conductive hearing loss). (3) PB word lists. Note the increase in word-recognition scores with increased intensity to a maximum of less than 90% (suggesting sensory/neural hearing loss). (4) PB word lists. Note the increase in word-recognition scores with increased intensity to a given level, beyond which scores decrease. This is the “rollover” effect, and it occurs in some ears when there are lesions in the higher auditory centers (see Chapter 12).

For a demonstration of how to perform the SRT test, see the video titled “Speech Reception Threshold Testing” in the Clinical Demonstrations section on the Companion Website.



Recording SRT Results

After SRTs for each ear have been obtained, they should be recorded in the appropriate space on the audiometric worksheet (Figure 5.2p). Many audiologists prefer to make routine measurements of the SRT binaurally or in the sound field. The audiometric worksheet used in this book does not provide for such notation, but many forms are available that do.

Relationship of SRT to SDT and the Pure-Tone Audiogram. The SRT is always higher (requires greater intensity) than the SDT. In the earliest years of the profession, Egan (1948) showed that the magnitude of the difference between the SRT and SDT does not normally exceed 12 dB. However, this difference may change with the shape of the pure-tone audiogram.

7. The SRT is expected to be found at a _____ intensity than the SDT.

For many years different methods have been used to predict the SRT from the pure-tone audiogram. Although some of these procedures have been quite elegant, most audiologists have

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AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☐ Supra Aural ☐	RIGHT										LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000		
Masking Type WB ☐ NB ☐																				
EM Level in Opp. Ear																				

BONE CONDUCTION

Placement Forehead ☐ Mastoid ☐	RIGHT						FOREHEAD						LEFT					
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type WB ☐ NB ☐																		
EM Level in Opp. Ear																		

	2 Freq	3 Freq	Variable	WEBER					2 Freq	3 Freq	Variable	
Pure Tone Average									Pure Tone Average			

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☐	RIGHT						LEFT						
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2					
	p	q	List HL	s	List HL			List HL				List HL	
EM Level in Opp. Ear	t			u									

FREQUENCY IN HERTZ

	125	250	500	1000	2000	4000	8000
10							
0							
10							
20							
30							
40							
50							
60							
70							
80							
90							
100							
110							
120							

750 1500 3000 6000

Speech Presentation

V MLV Recorded

SRT ☐ ☐

WRS ☐ ☐

COMMENTS

AUDIOGRAM KEY

Right Left AC Unmasked ○ × AC Masked △ □ BC Masked Unmasked < > BC Mastoid Masked [] BC Forehead Masked { }	Both BC Forehead Unmasked Y Sound Field (unaided) S Sound Field (aided) • Cyc Ear Masked * Examples of No Response Symbols ○ × △ □

FIGURE 5.2 An example of an audiometric worksheet showing the items to be completed when performing speech audiometry:

o. Masking type used in the nontest ear p. SRT q. Test list number used for WRS r. Hearing level setting WRS test s. Word-recognition scores (WRS)	t. Effective masking level in the nontest ear used for SRT u. Effective masking level in the nontest ear used for WRS v. Presentation method for SRT and WRS testing

agreed that the SRT can be predicted by finding the average of the lowest two thresholds at 500, 1000, and 2000 Hz (Fletcher, 1950). Carhart and Porter (1971) found that the SRT can be predicted from the pure-tone audiogram by averaging the thresholds at 500 and 1000 Hz and subtracting 2 dB. Although 500, 1000, and 2000 Hz have been called the “speech frequencies,” Wilson and Margolis (1983) cautioned that such phrasing can be misleading if it is inferred that this narrow range of frequencies is all that is essential for the adequate discrimination of speech.

In some cases the SRT may be much lower (better) than the pure-tone average (PTA), such as when the audiogram falls precipitously in the high frequencies. In other cases the SRT may be higher (poorer) than even the three-frequency PTA, for example, with some elderly patients or those with disorders of the central auditory nervous system. The special significance of PTA-SRT disagreement regarding erroneous or nonorganic hearing loss is discussed in Chapter 13.

8. The reliability of the SRT can usually be determined by comparing it to the thresholds at frequencies _____ and _____.

Clinical Commentary

The value of the SRT is frequently questioned since its determined level lends little to the diagnostic picture. Its true value lies in two areas. First, the SRT is useful as a comparative measure with pure-tone results to signal the accuracy of both tests. Second, the SRT may be used in counseling patients with regard to the degree of hearing loss they may have.

Bone-Conduction SRT

At times it is useful to determine the SRT by bone conduction. Because the bone-conduction circuits on diagnostic audiometers are often not calibrated for speech, some degree of manipulation may be required for bone-conduction speech audiometry (Barry & Gaddis, 1978). On most clinical audiometers the speech input may be used with the bone-conduction output.

Bone-conducted SRTs are especially useful in testing children who will “play a game” with words but not with tones. A comparison between children’s hearing thresholds for speech by bone conduction and by air conduction may provide useful information regarding a possible conductive component to a hearing loss given the high correlation found between the PTA by bone conduction at 500, 1000, and 2000 Hz and the bone-conducted SRT (Goetzinger & Proud, 1955). Hahlbrock (1962) found the bone-conducted SRT helpful in separating auditory from tactile responses by bone conduction. Of course, with bone-conducted speech audiometry there is no way to be certain which ear is being tested unless proper masking is invoked, which is impossible with some patients. However, even the limited information derived from this procedure and the inferences it allows often justify the use of bone-conducted speech audiometry.

Most Comfortable Loudness Level

Some audiologists gain useful information from determining the hearing level at which speech is most comfortably loud for their patients. Most people with normal hearing find speech comfortable at 40 to 55 dB above threshold.

Measurement of **most comfortable loudness (MCL)** should be made with continuous discourse, so that the patient has an opportunity to listen to speech as it fluctuates over time. The use of cold running speech, as described for SRT or SDT measurements, is practical for this purpose.

The patient is instructed to indicate when the speech is perceived to be at a comfortable level. The test may start at a hearing level slightly above the SRT. From there the intensity is

increased gradually. At each hearing level the patient should respond, indicating whether the speech is “too soft,” “too loud,” or “most comfortable.” Several measurements should be made, approaching the MCL from both above and below the level first selected.

The MCL may be determined monaurally or binaurally under earphones or in the sound field. Martin and colleagues (1998) found that most audiologists do not use the MCL measurement, except in the evaluation of hearing aids.

Uncomfortable Loudness Level

Under some conditions it is useful to find the level of speech that is uncomfortably loud for listeners. For normal-hearing subjects, this intensity often extends to the upper limit of the audiometer (100 to 110 dB HL). In some patients with hearing disorders the **uncomfortable loudness level (UCL)** is much lower, especially when expressed in decibels above the SRT. While some audiologists use measures of UCL for speech when assessing patients for hearing aid candidacy, this measure is not nearly as clinically useful as more frequency-specific measures of UCL as discussed in Chapter 14.

It is not known just how the abbreviation for uncomfortable loudness level became UCL, since “uncomfortable” is one word, but these kinds of derivations are often obscure. Some patients find a given level of speech uncomfortable because of its loudness, others because of discomfort produced by the physical pressure of the sound. When possible, it is helpful to determine which effect is active in a given case. The UCL is also called the **threshold of discomfort (TD)**, the **tolerance level**, and the **loudness discomfort level (LDL)**.

Although there are better methods for ascertaining if amplification from hearing aids exceed a patient’s tolerance levels (see Chapter 14), some audiologists continue to measure aided UCL in the sound field. Materials used for the UCL can be identical to those used for the MCL. Patients should be instructed to signal, either verbally or by some other method, when the speech is uncomfortably loud. They should be reminded that the UCL may be considerably above the level at which they find the loudness of speech most enjoyable, but that they should signal only when exceeding a given level would be intolerable. Acoustic feedback can be a real problem when UCLs are measured in the sound field.

Clinical Commentary

Clinicians need be aware that UCLs measured with speech stimuli reflect loudness perceptions based on hearing levels in the lower frequencies. Measures of frequency specific acoustic tolerance levels yield more useful data for planning hearing loss rehabilitation.

Range of Comfortable Loudness

9. Test materials for MCL, UCL, and RCL all include _____.

The **range of comfortable loudness (RCL)**, also known as the **dynamic range (DR)**, is the arithmetic difference between a threshold measure and the UCL. A normal-hearing person has an RCL of 100 dB or more for either speech or pure tones. The RCL determination is sometimes used in selecting hearing aids and in other rehabilitative measures.

9. cold running speech

When an SRT cannot be obtained, the difference between the SDT and the UCL provides a reasonable estimate of the RCL for speech. When prescribing hearing aid settings, determining more frequency specific RCL becomes more important.

Speech-Recognition Testing

Many patients report that the difficulties they have in understanding speech are solved when speech is made louder. This can be accomplished by decreasing the distance from the listener to the speaker, by having talkers increase their vocal output, or by using a system of sound amplification. Most patients with conductive hearing losses show improved speech recognition when loudness is increased.

A common complaint of many patients is difficulty in understanding what people are saying. Many individuals with sensory/neural problems, however, complain that even when sounds are made louder they are not clearly recognizable. This difficulty in discriminating among the sounds of speech plagues many patients much more than a reduction in loudness. These are the patients who claim, "I can hear, but I can't understand."

Through the years, a number of different terms have been used to describe the measurement of speech discrimination. The expressions **speech-recognition score (SRS)** and **word-recognition score (WRS)** have appeared in the literature with increasing frequency and appear to be the current expressions of choice. Konkle and Rintelmann (1983) contend that the word *discrimination* in this context implies distinguishing among different stimuli, whereas recognition suggests the report of a patient on what has been heard after the presentation of a single item. For the most part, throughout this book, the term *speech-recognition score* will replace the older *speech-discrimination score (SDS)* to describe tests performed to determine an individual's understanding of speech stimuli. Use of the term *word-recognition score* is usually reserved for use when test materials are known to be words and not some other speech construct.

The development of test materials to assess speech-recognition ability has been arduous. For any test to be useful, it should be both reliable and valid. Reliability means that a test is able to reveal similar scores on subsequent administrations (test-retest reliability) and that different forms of the same test result in equivalent scores. The validity of any speech-recognition test relates to the following:

1. How well it measures what it is supposed to measure (a person's difficulties in understanding speech).
2. How favorably a test compares with other similar measures.
3. How the test stands up to alterations of the signal (such as by distortion or presentation with noise) that are known to affect other speech tests in specific ways.

The quantitative determination of a patient's ability to discriminate speech helps the audiologist in several ways:

1. It determines the extent of the speech-recognition difficulty.
2. It aids in diagnosis of the site of the disorder in the auditory system.
3. It assists in the determination of the need for and proper selection of amplification systems.
4. It helps the clinician to make a prognosis for the outcome of treatment efforts.

10. Tests for SRS differ from those for SRT and SDT in that the former are _____.

Several methods have been advanced for measuring speech recognition. These include testing with nonsense syllables, digits, monosyllabic words, and sentences. Prerecordings of many of these are commercially available.¹ Procedures have included both open- and closed-response message sets. In the open-response format, the patient may select an answer from an infinite number of possible utterances. In a closed-response system, however, the patient must choose the correct response from a group of words, sentences, or pictures.

Egan (1948) showed a relationship between the number of sounds in a word and the ability to recognize that word. The more phonemes and the more acoustic redundancy contained in a word, the more easily it is recognized. Word recognition gets poorer as more and more high frequencies are eliminated from speech, which decreases intelligibility without affecting overall loudness very much. It has long been known that as frequencies below about 1900 Hz are removed from speech, the effect on speech recognition is much less than when higher frequencies are removed (e.g., French & Steinberg, 1947).



An auditory demonstration of how eliminating high frequencies affects speech recognition may be found under Simulated Hearing Loss on the Companion Website.

Phonetically Balanced Word Lists

Original attempts at speech-recognition testing (Egan, 1948) involved compiling lists of words that are **phonetically balanced (PB)**, that is, lists that contain all the phonetic elements of connected English discourse in their normal proportion to one another. Egan's work at the Psychoacoustic Laboratories at Harvard University resulted in 20 lists of 50 words each. When these words are used, the word-recognition score is determined by counting the number of correctly identified words out of 50 and multiplying this number by 2%.

Hirsh and others (1952) eliminated most of Egan's original 1,000 words and added a few more for a total of 200 words, of which 180 were derived from Egan's list. These 200 words were divided into four lists of 50 words each, with each list scrambled into six sublists. The resultant PB word lists are known as CID Auditory Test W-22. Ross and Huntington (1962) found some slight differences among the W-22 word lists in terms of word-recognition scores, but the magnitude of the differences among lists is small enough that they may be used interchangeably in clinical practice.

Martin, Champlin, and Perez (2000) compared word-recognition scores using PB word lists and similar lists of words that were deliberately not phonetically balanced. They compared scores on subjects with normal hearing and those with sensory/neural hearing loss. The scores for the lists were almost identical, which brings into question whether the lists are, or need to be, phonetically balanced.

Because many of the words in adult word lists are unfamiliar to children, Haskins (1949) developed four lists of 50 words, all within the vocabularies of small children. The test may be presented by tape, disc, or by monitored live-voice, and it is scored in the same way as word lists when adults or older children are tested. The test difficulty increases sharply for children younger than 3½ years of age (Sanderson-Leepa & Rintelmann, 1976).

Many clinicians erroneously refer to the test materials as "PB words." It must be remembered that it is the lists, and not the words themselves, that are purportedly balanced. This is an old tradition and not likely to change, but it is inaccurate.

11. Words on a PB word list have _____ syllable(s).

12. While speech threshold tests are scored in _____, SRS tests are scored in _____.

Consonant-Nucleus-Consonant Word Lists

The phonetic construction of the English language is such that there is no way to truly balance a list of words phonetically, especially a relatively short list, because of the almost infinite number of variations that can be made on every phoneme (allophones) as they are juxtaposed with other phonemes. Lehiste and Peterson (1959) prepared ten 50-word lists that were phonemically balanced, a concept they judged to be more realistic than phonetic balancing. Each monosyllabic word contained a consonant, followed by a vowel or diphthong, followed by another consonant. These were called **consonant-nucleus-consonant (CNC) words** and were scored the same way as the original PB word lists. Later, the CNC lists were revised (Lehiste & Peterson, 1962) by removing proper names, rare words, and the like.

Tillman, Carhart, and Wilber (1963) took 95 words from the CNC lists (Lehiste & Peterson, 1959) and added 5 of their own, thereby generating two lists of 50 words each. Tillman and Carhart (1966) later developed four lists of 50 words each (Northwestern University Test No. 6), which they found to have high intertest reliability. Each of the four lists is scrambled into four randomizations. Auditory test NU-6 and CID W-22 remain the most popular materials for word-recognition testing (Martin et al., 1998) and yield similar results on patients when testing in both quiet and with background noise, although scores are slightly higher on the NU-6 test. It is important to remember, however, that patients' responses to this test, as to other word-recognition tests, may change on the basis of a number of variables, not the least of them being differences among the talkers who make the recordings. This problem is increased when the test is performed in the presence of background noise. An obvious solution to this would be for all audiologists to test with commercially available prerecorded word lists.

High-Frequency Emphasis Lists

Gardner (1971) developed two lists of 25 words each, with each word carrying a value of 4%. The test used with these lists is designed to measure the word-recognition scores of patients with high-frequency hearing losses who are known to have special difficulties in understanding speech. Each of the words contains the vowel /I/ (as in *kick*) and is preceded and followed by a voiceless consonant. Gardner suggested that the test is more useful if the words are spoken by a woman with a high-pitched voice. A similar approach to high-frequency word lists was taken by Pascoe (1975).

Nonsense-Syllable Lists

Edgerton and Danhauer (1979) developed two lists, each with 25 nonsense syllables. Every item contains a two-syllable utterance with each syllable produced by a consonant, followed by a vowel (CVCV). Carhart (1965) earlier suggested that nonsense words are too abstract and difficult for many patients to discriminate, and this is sometimes true of the CVCV test. It does have the advantage that each phoneme can be scored individually, eliminating the obvious errors in the all-or-none scoring used in word tests.

Testing Word Recognition with Half Lists

Time can be saved in word-recognition testing by limiting the test lists to 25 words, using one half of each list with a weight of 4% per word. Opposition to this procedure is based on the following arguments: (1) that one half of a list may produce fewer audible sounds than the other half, (2) that there may be some real differences in difficulty of discrimination between the two halves of a list, but primarily (3) that splitting the lists causes them to lose their phonetic balance (which

is not truly obtainable). Tobias (1964) pointed out that phonetic balancing is unnecessary in a “useful diagnostic test” and that half lists do measure the same thing as full lists. Thornton and Raffin (1978) showed half lists to be as reliable as the full 50-word lists. Martin and colleagues (1998) found that most audiologists prefer to test with 25-word lists.

Short Isophonemic Word Lists

The Short Isophonemic Word Lists (Boothroyd, 1968) were designed to reduce word-recognition test time without sacrificing validity. Each of fifteen lists of 10 consonant-vowel-consonant words contains 30 phonemes. Rather than the traditional scoring of test words as correct or incorrect, each phoneme is scored individually, allowing for a potential of 30 speech-recognition errors per list. The time saved in administration of the isophonemic lists can be considerable when multiple word lists are employed for attaining word-recognition performance at a number of intensities. No significant differences were found between measures of word recognition utilizing the Short Isophonemic Word Lists and the more commonly employed CID W-22 test (Tonry, 1988).

Testing of Monosyllables with a Closed-Response Set

The closed-set paradigm for word-recognition testing followed the development of a rhyme test by Fairbanks (1958). House, Williams, Hecker, and Kryter (1965) developed the Modified Rhyme Test, in which the patients are supplied with a list of six rhyming words and select the one they think they have heard. Fifty sets of items are presented to the patient, along with a noise in the test ear. Half of the word sets vary only on the initial phoneme, and the other half differ in the final phoneme.

A test designed to be sensitive to the discrimination problems of patients with high-frequency hearing losses is the **California Consonant Test** (Owens & Schubert, 1977). One hundred monosyllabic words are arranged in two scramblings to produce two test lists. The patient, selecting from four possibilities, marks a score sheet next to the selected word. While normal-hearing individuals obtain high scores on this test, patients with high-frequency hearing losses show some difficulty.

The **Picture Identification Task (PIT)** was developed by Wilson and Antablin (1980) to test the word recognition of adults who could not produce verbal responses and had difficulty in selecting items from a printed worksheet. The CNC words are represented by pictures that are arranged into sets of four rhyming words. The developers of the PIT found that it provides good estimates of word recognition for the nonverbal adult population.

Recognizing the need for testing the word-recognition abilities of small children who are either unable or unwilling to respond in the fashion of adults, Ross and Lerman (1970) developed the **Word Intelligibility by Picture Identification (WIPI) test**. The child is presented with a series of cards, each of which contains six pictures. Four of the six pictures are possibilities as the stimulus item on a given test, and the other two pictures on each card (which are never tested) act as foils to decrease the probability of a correct guess. Twenty-five such cards are assembled in a spiral binder. Children indicate which picture corresponds to the word they believe they have heard. This procedure is very useful in working with children whose discrimination for speech cannot otherwise be evaluated, provided that the stimulus words are within the children’s vocabularies. Incorrect identification of words simply because they are not known is common with children under 3-1/2 years of age.

The **Northwestern University Children’s Perception of Speech (NUCHIPS) test** (Elliott & Katz, 1980) is similar to the WIPI. Each child is presented with a series of four picture sets, including 65 items with 50 words scored on the test.

13. Picture identification speech-recognition tests are usually used with _____.

Testing Speech Recognition with Sentences

A number of different sentence tests have been devised to measure speech recognition. Jerger, Speaks, and Trammell (1968) were among the first to object to the use of single words as a discrimination test on the basis that they do not provide enough information regarding the time domain of speech. Normal connected speech consists of constantly changing patterns over time, thus necessitating the use of longer samples than single words can provide for a realistic test. Jerger and colleagues also iterated the problems inherent in testing with an open-message set. Criticisms of sentence tests include the effects of memory and learning, familiarity with the items as a result of repetition, and the methods of scoring. Much of the opposition to sentence tests is that their structure enables a listener who is a good guesser to make more meaning of a sentence than does another patient with similar speech-recognition abilities.

The test devised by Jerger and colleagues (1968) involves a set of ten synthetic sentences. Each sentence contains 7 words, with a noun, predicate, object, and so on, but carries no meaning. All words were selected from Thorndike's list of the 1,000 most familiar words. The sentences are recorded on CD or audiotape, and patients show their responses by indicating the number that corresponds to the sentence they have heard. Some sentences are more difficult than others. Because early experimentation showed that **synthetic sentence identification** is not sufficiently difficult when presented in quiet, a competing message of connected speech is presented, along with the synthetic sentences, and the intensity of the competing message is varied.

A variety of speech-recognition test materials, including CID Auditory Test W-22, NU-6, PBK, WIPI, high-frequency emphasis word lists, and example sentences for synthetic sentence identification (SSI) are provided in the Professional Resources section on the Companion Website.



Another sentence test, which continues in use, is the Central Institute for the Deaf (CID) Everyday Sentence Test (Davis & Silverman, 1978). Fifty key words are contained within ten sets of ten sentences each. The percentage of correctly identified key words determines the score.

Testing Speech Recognition with Competition

Many audiologists feel that speech-recognition tests carried out in quiet do not tax patients' speech-recognition abilities sufficiently to diagnose the kinds of communication problems that are experienced in daily life. For this reason, a noise or other competing signal is often added to the test ear to make recognition more difficult. When this is done, the relative intensity of the signal (speech) and the noise is specified as the **signal-to-noise ratio (SNR)**. The signal-to-noise ratio is not a ratio at all, but rather the difference in intensity between the signal (that which is wanted) and the noise (that which is not wanted) (see Table 5.1 for examples).

TABLE 5.1 Examples of Three Signal-to-Noise Ratios (SNR)

<i>Signal</i>	<i>Noise</i>	<i>SNR</i>
50 dB HL	50 dB HL	0 dB
40 dB HL	50 dB HL	-10 dB
10 dB HL	0 dB HL	+10 dB

Signals used to help degrade the score include modulated white noise (Berry & Nerbonne, 1971), a mixture of noise in one or two speakers (Carhart, Tillman, & Greetis, 1969), one to three talkers (Carhart, Johnson, & Goodman, 1975), two- and four-talker combinations (Young, Parker, & Carhart, 1975), a single talker (Speaks & Jerger, 1965), and a multitalker babble (Cox, Alexander, & Gilmore, 1987). Speech has been shown to be a better competing signal than electronically generated noise with a spectrum that resembles speech (Carhart et al., 1975).

Kalikow, Stevens, and Elliott (1977) developed a test made up of eight lists of 50 sentences each; only the last word in each sentence is the test item, resulting in 200 test words. The test items are recorded on one channel of a two-channel tape or CD, and a voice babble is recorded on the second channel. In this way the two hearing-level dials of an audiometer can control the ratio of the intensities of the two signals. This procedure, called the **Speech Perception in Noise (SPIN) test**, has undergone considerable modification (Bilger, Nuetzel, Rabinowitz, & Rzezchowski, 1984). Schum and Matthews (1992) reported an interesting effect: A significant percentage of the elderly patients with hearing loss they tested did not use contextual cues as effectively on the SPIN as did their younger counterparts.

The Quick SIN (Speech In Noise) test (Etymotic Research, 2001) was designed to obtain an estimate of a patient's experienced difficulty hearing in noise that is representative of the patient's performance in the "real world." The test is comprised of six sentences presented in the presence of a four-talker babble noise, with five key words per sentence (Table 5.2). The sentences are presented at five pre-recorded signal-to-noise ratios encompassing a range from normal to severely impaired performance in noise. The resultant score from the Quick SIN test represents a decibel increase in the signal-to-noise ratio required by someone with hearing loss to understand speech in noise with comparable performance to someone with normal hearing. The test takes only a minute to complete and can be used for counseling patients toward appropriate amplification options.

Another useful sentence-in-noise test is the **Connected Speech Test (CST)** (Cox et al., 1987; Cox, Alexander, Gilmore, & Pusakulich, 1988). The most recent version of the test is an audiovisual recording with a six-talker speech babble competition. The test may be given either audiovisually or audio only. Comprised of eight sets of six passages, the patient listens to each passage, given one sentence at a time, and is instructed to repeat as much of each sentence as he or she understands. Each passage contains 25 key words that are used for scoring with intelligibility scores based on the number of key words repeated correctly.

The Hearing in Noise Test (HINT; Nilsson, Soli, & Sullivan, 1994) measures the listener's ability to hear sentences in quiet and in noise in the sound field. Speech noise is presented at 65 dB HL, and the intensity of the sentences is varied to find the hearing level required for 50% of a list of 10 sentences to be repeated correctly. The test score is given as the decibel difference between the background noise and the sentence level required to attain 50%. For

TABLE 5.2 Sample Sentences from the Quick SIN Test

Sentences are presented in increasing levels of noise, with the first sentence presented at a 25 dB signal-to-noise ratio and the sixth sentence presented at a 0 dB signal-to-noise ratio. The test has a total of 18 equivalent lists.

1. A white silk jacket goes with any shoes.
2. The child crawled into the dense grass.
3. Footprints showed the path he took up the beach.
4. A vent near the edge brought in fresh air.
5. It is a band of steel three inches wide.
6. The weight of the package was seen on the high scale.

example, a required hearing level of 70 dB HL for 50% correct sentence identification would result in a 5 dB SNR score (i.e., 70 – 65). The higher the SNR, the more difficulty the listener has hearing in noise.

Recording Speech-Recognition Test Results

After the speech-recognition tests are completed, the results are recorded on the audiometric worksheet in terms of the percentage of correctly identified words. In addition, the clinician records the test or list number; the level at which the test was performed; and, if opposite-ear masking was used as discussed in Chapter 6, the effective masking level and the type of noise. If additional speech-recognition tests are carried out with a competing signal in the same ear, the SNR is indicated, along with results and other identifying information. Many audiologists routinely assess speech recognition binaurally to demonstrate the natural advantage of processing speech binaurally. The audiometric worksheet used in this book does not provide for notation of binaural tests, but many forms are available that do.

Clinical Commentary

As described in Chapter 4, bone-conduction results are essential for determining the extent of sensory/neural involvement in a hearing loss. Some clinicians have found, however, that they do not need to test by bone conduction if speech-recognition scores are consistent with the degree of loss and immittance results (see Chapter 7) show no evidence of conductive hearing loss.

Administration of Speech-Recognition Tests

In carrying out speech-recognition tests, audiologists must first help patients to understand what is expected of them, what the test will consist of, and how they are to respond. Audiologists must decide on

1. The method of delivery of the speech stimuli (prerecorded material is recommended over monitored live-voice).
2. The type of materials to be used.
3. The method of response.
4. The intensity at which the test will be performed.
5. Whether more than one level of testing is desired.
6. Whether a noise is desired in the test ear (or loudspeaker) to increase the difficulty of the test and, if so, the intensity of the noise.
7. Whether masking of the nontest ear is necessary and, if so, the amount and type of noise to use.

Instructions to patients should be delivered orally, even if printed instructions have been read prior to the test. Gestures and pantomimes or the use of sign language may be necessary, although it is likely that any patient who is unable to comprehend oral instructions will be unable to participate in a speech-recognition test. If responses are to be given orally, patients should be shown the microphone and the proper response should be demonstrated. If the responses are to be written, the proper forms and writing implements, as well as a firm writing surface, should be provided. Determining that the patient understands the task may save considerable time by avoiding test repetition.

Selection of Stimuli, Materials, and Response Method

The presentation level of the stimuli should be properly controlled and monitored on the VU meter of the audiometer. If a recording is used, it must contain a calibration signal of sufficient duration for the gain control of the VU meter to be adjusted so that the needle peaks at zero VU. If monitored live-voice is used, proper microphone technique is very important. The audiologist should be seated in front of the microphone and should speak directly into its diaphragm. If monosyllables are being tested, a carrier phrase should be used to prepare the patient for the stimulus word. The last word of the carrier phrase should be at the proper loudness so that the needle of the VU meter will peak at zero, corresponding to the calibration signal. The test word should be uttered with the same monotonous stress and should be allowed to peak where it will since words vary in acoustic power. Test words are not normally expected to peak at zero VU. Sufficient time (about 3–5 seconds) should be allowed between word presentations to permit the patient to respond.



Prerecorded test materials for speech-recognition testing are preferred over monitored live-voice (MLV) in almost all instances. If MLV is used, proper technique is important. The video titled “Word-Recognition Testing” on the Companion Website demonstrates proper technique for MLV testing for speech-recognition tests.

Patients may respond by repeating the stimulus word, writing down their responses on a form (with 50 numbered spaces for standard word lists), circling or marking through the correct answer on a closed-message set, or pointing to a picture or object. It is difficult to gauge the criteria that patients use in determining their responses—that is, whether they are relatively strict or lax in expressing their recognition of specific items. Jerger and colleagues (1988) studied these criteria in elderly subjects and concluded that attempting to control for this variable is probably not essential.

Although no real satisfaction has been universally expressed for speech-recognition materials, audiologists have individual preferences. A survey on audiometric practices (Martin et al., 1998) showed the W-22 word lists to be most popular, with the NU-6 lists a close second. It is probable that the sensitivity of these two tests in ferreting out true differences in hearing function is not as great as may be found with other tests (Wiley, Stoppenbach, Feldhake, Moses, & Thordardottir, 1994). One type of test material may be preferred for routine hearing tests under earphones and another type for special diagnostic tests.

Performance-Intensity Functions in Speech-Recognition Testing

Many of the word lists currently used in speech-recognition testing were developed during World War II to test the efficiency with which electronic communications systems could transmit speech. Thus, the primary objective was to design military communication systems that would, while transmitting a minimum of acoustic content, enable the listener to understand the message. Hence, the term “articulation” was used to express the connection achieved between the listener and the speaker—that is, the joining together of the two by means of a communication system. Use of the word “articulation” in this context is sometimes confusing to students of speech-language pathology, who learn to use this word to mean the manner in which speech sounds are produced with such structures as the tongue, lips, palate, and teeth.

Research has been conducted to determine the articulation-gain functions of word-recognition lists—that is, the percentage of correct identifications of the words at a variety of

sensation levels. As Figure 5.1 illustrates, for normal-hearing individuals, the maximum score (100%) is obtained about 35 to 40 dB above the SRT. For many people with sensory/neural hearing losses, the maximum obtainable score is below 100% regardless of presentation level. In deference to earlier research attempting to attain a phonetic balance to word lists, the highest word score obtainable, regardless of intensity is often called the **PB Max** (Eldert & Davis, 1951). The term **performance-intensity function for PB word lists (PI-PB)** has replaced the old articulation-gain function terminology. In acknowledgment of the fact that performance-intensity functions can be completed with a variety of speech test materials, these functions may also be called PI-SR functions, or PI functions for speech recognition. These measures are discussed again in later chapters of this book in terms of their diagnostic value.

14. True/False

When testing SRS, it is frequently necessary to perform more than one test using different presentation levels to ensure a measure of maximum performance.

Test Presentation Level

Regardless of whether speech-recognition testing is done at a set sensation level (above the SRT) for each ear or a preset intensity that is the same in both ears, the amount of the audible signal in the ear will vary depending upon the degree of hearing loss and its configuration. If testing is done at only one intensity, there is no way to know that the speech-recognition score (SRS) represents the patient's maximum performance unless that score is 100%. Ideally, speech-recognition testing should be performed at a minimum of two levels. A good first level for testing SRS is a presentation level 5 to 10 dB above the patient's most-comfortable listening level. The MCL plus 5 to 10 dB usually affords an approximation of maximum performance, assuming most speech sounds are audible at this intensity. A second level of higher intensity (usually 90 dB HL) should then be used to reveal a possible rollover in performance, as illustrated in Figure 5.1, indicative of disorders beyond the cochlea. Other levels (higher or lower) may be tested at the audiologist's discretion in an attempt to more fully define the PI function. Testing at conversational levels (45 to 50 dB HL) may be done for counseling purposes to demonstrate difficulties experienced and the potential benefits from amplification.

Problems in Speech-Recognition Testing

Although the test-retest reliability of word tests is good for patients with normal hearing and conductive hearing losses, this consistency sometimes fails for patients with primarily sensory/neural impairments (Engelberg, 1968). Thornton and Raffin (1978) concluded that the significance of differences in speech-recognition scores for a given individual depends on the number of items in the test and the true score for that test. From a statistical viewpoint the greatest variability in scores should be found in the middle range of scores (near 50%) and the smallest variability at the extremes (near 0% and 100%). Thornton and Raffin (1978) demonstrated that two speech-recognition scores in the mid range obtained from the same patient may need to differ by more than 20% to be considered significantly different. In general, the variability may be assumed to decrease as the number of test items increases. Therefore, it is sometimes risky for audiologists to assume that an increase or decrease in a given patient's speech-recognition scores represents a real change in speech-recognition ability.

Attempts have been made to relate the results obtained on speech-recognition tests to the kinds of everyday difficulties experienced by patients. Statements such as "Our test shows you can understand 72% of what you hear," are oversimplified and naive, for they ignore such important

TABLE 5.3 General Guide for the Evaluation of Word-Recognition Tests (Goetzinger, 1978)*

<i>Word-Recognition Scores (in Percent)</i>	<i>General Word-Recognition Ability</i>
90 to 100	Normal limits
75 to 90	Slight difficulty, comparable to listening over a telephone
60 to 75	Moderate difficulty
50 to 60	Poor recognition; marked difficulty in following conversation
<50	Very poor recognition; probably unable to follow running speech

*Note caveats in text regarding a rigid interpretation of this guide.

real-world variables as contextual cues, lipreading, ambient noise level, speaker intelligibility, and so on. Goetzinger (1978) generated a general guide for evaluating speech-recognition scores, which is presented in Table 5.3. This table, though helpful, should not be interpreted rigidly. Many patients perform considerably better on speech-recognition tests than they do in daily conversation, and others not nearly as well. Speech-recognition tests are helpful in diagnosis, but are far from perfect for predicting real-world communication.

Bone-Conduction Speech-Recognition Testing

At times, in cases of severe mixed hearing loss, a patient's best possible speech-recognition score may not be attainable because of the severity of the air-conduction hearing loss. In many of these cases it is possible to test speech recognition by bone conduction in the same way described earlier for testing SRTs. Speech-recognition testing by bone conduction has never become popular, but interest has been shown in this procedure from time to time.

Speech-Recognition, the Audibility Index (AI), and Implications for Speech-Language Therapy

15. As the Audibility Index decreases, perceived handicap _____.

It is possible to estimate a person's speech-recognition ability based upon the amount of the speech signal that is audible with a given hearing loss. Originally deriving its name from the terminology used for articulation-gain function testing, such estimations were referred to as the *articulation index*. Today, they are more frequently called the *audibility index*.

The computational steps proposed in the original articulation index formulae have been simplified for ease of comprehension of the resultant value (Clark, 1992; Killion, Mueller, Pavlovic, & Humes, 1993). Following these recommendations, the audibility index (AI) is computed by simply counting the number of dots below the hearing levels plotted on a "count-the-dot audiogram" (Figure 5.3). The value derived represents the percentage of conversational speech energy audible to the listener with a given hearing impairment at a distance of 3 to 6 feet.

Generally, as AI decreases, perceived hearing handicap increases (Holcomb, Nerbonne & Konkle, 2000). Clinically, the AI should reflect the speech-recognition score for conversational speech intensity (approximately 45–50 dB HL). The count-the-dot audiogram can be useful as

15. increases

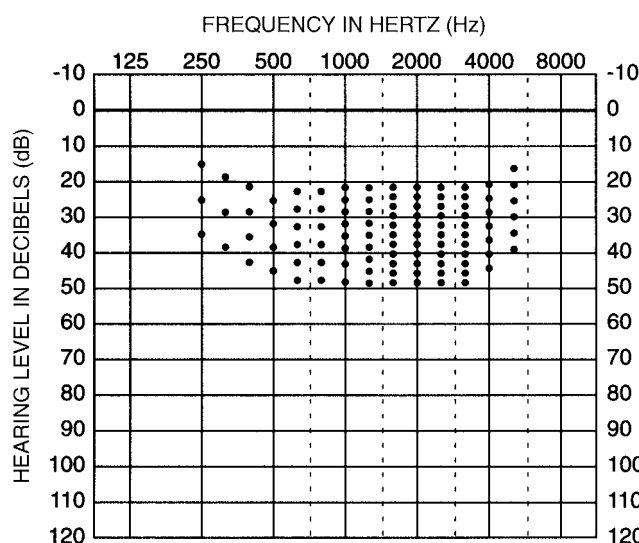


FIGURE 5.3 A “count-the-dot audiogram.” The number of dots above a patient’s threshold is the audibility index revealing the percentage of conversational speech energy audible to the patient at a distance of 3 to 6 feet.

a visual tool that can be used when discussing the impact of a given hearing impairment or when comparing hearing levels with and without corrective amplification.

Plotting a patient’s pure-tone test results on an audibility index audiogram is a quick means for the speech-language pathologist to see what frequency components of speech are audible to individuals in speech-language therapy. The voiceless consonants of human speech all lie at or above 1500 Hz, with the acoustic energy of such consonants as *f*, *s*, and *th* lying primarily above 4000 Hz. To concentrate on speech-discrimination training and speech-production therapy through auditory-based approaches for a client who cannot perceive the targeted speech sounds even with properly fitting hearing aids rapidly becomes an exercise in futility. Determination of what sounds are audible to the client can quickly guide the speech-language pathologist in the determination of the most efficacious approach to therapy. An alternate view of speech sound audibility is provided in Figure 5.4.

Understanding what speech energy is audible with and without hearing aids allows the speech-language pathologist to better explain to classroom teachers, parents, or the significant others of adult clients what listening behaviors are expected. More discussion on the implications of speech understanding and the management of hearing loss is presented in Chapter 15.

Computerized Speech Audiometry

Speech audiometry, like any behavioral measurement, must at times be practiced as more of an art than a science. In a majority of cases, however, it is possible to carry out these measurements in a methodical, scientific manner, using the process of logical decision making. To illustrate this, Wittich, Wood, and Mahaffey (1971) programmed a digital computer to administer SRT and SRS tests, including proper masking, to analyze the patient’s responses and to present the results in an audiogram format at the conclusion of the test. Their results were compared to those of an experienced audiologist on a number of actual clinical patients, and very high correlations were observed. In addition, computerized speech audiometry can allow the flexibility of live-voice testing without its obvious limitations.

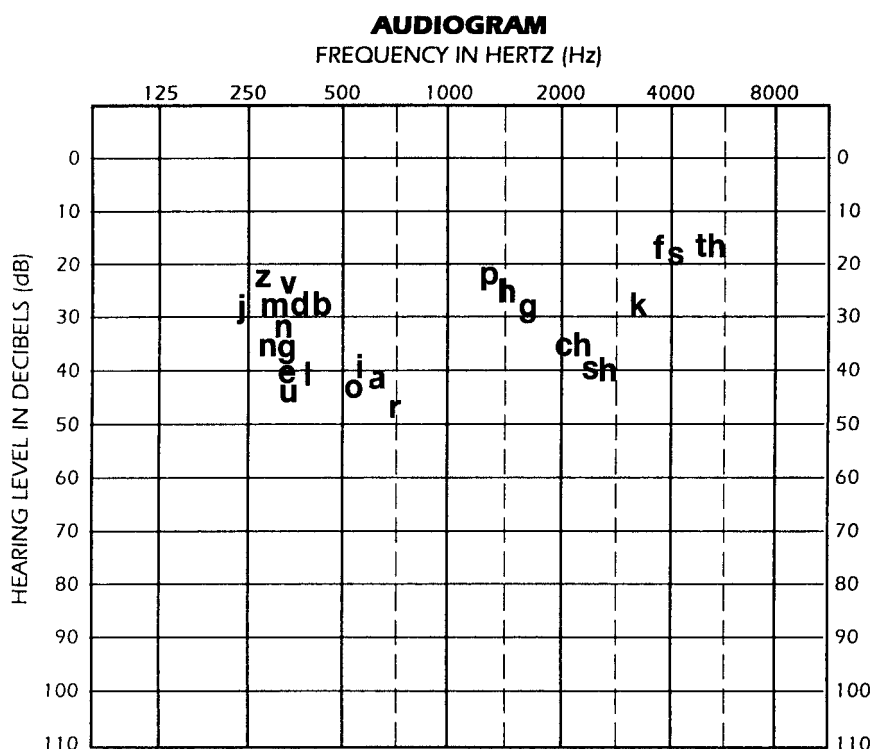


FIGURE 5.4 The “Speech Sound Audiogram” provides a quick visual depiction of the audibility of speech with a given hearing loss. In this audiogram, speech sounds of greater intensity than the hearing threshold are audible to the patient. High-frequency hearing loss diminishes the audibility of the higher-frequency sibilants and voiceless affricates leading to the frequent patient complaint, “I can hear people, I just don’t always understand what they are saying.”

Clinical Commentary

As computer programs develop, a day may come in which many hearing tests are largely automated. While treatment cannot be initiated without hearing testing, some people erroneously believe that audiology is all about doing hearing tests. The freedom derived from automated testing would permit a greater concentration of effort toward audiology’s larger goal of effective patient treatment.

EVOLVING CASE STUDIES

In this section you will attempt to calculate the results from basic speech audiometric tests described in this chapter. Before reading the case studies below, based on the pure-tone results of Chapter 4 and what you now know about speech audiometry, propose the likely results of the following tests on the four theoretical case studies: speech-recognition threshold (SRT), speech-recognition score (SRS), most-comfortable loudness (MCL) and uncomfortable loudness (UCL). What hearing level(s) might you use for obtaining the SRS?

Case Study 1: Conductive Hearing Loss

The SRTs in both ears should be close to the two- or three-frequency pure-tone averages. In this case this would be about 35 dB HL. Speech-recognition scores can be expected to be very high, probably at or close to 100% for each ear. The MCLs in conductive hearing loss cases are usually close to the same sensation levels as they are for those with normal hearing, in this case about 80 dB HL. UCLs for either speech or tones will probably be unreachable, even at the upper limits of the audiometer.

Case Study 2: Sensory/Neural Hearing Loss

The SRTs for this patient, as in case 1, should be close to either the two-frequency or three-frequency pure-tone averages, about 35 dB HL for each ear. In sensory/neural cases, the SRS is usually reduced, often in direct proportion to the degree of hearing loss. Scores of 70% to 80% would be reasonable for this case. MCLs are usually reduced for most sensory/neural cases and might be on the order of 25 or 30 dB SL or about 60 or 70 dB HL. Repeating SRS testing at a slightly higher level would ensure a better reception of the high-frequency components of the speech signal (see Figure 5.7) and may result in a higher SRS. Completing the SRS at conversational intensities (45 to 50 dB HL) may help demonstrate to the patient and his spouse the impact of the loss and the potential for benefit from amplification. Uncomfortable loudness would also be expected to be reduced and might be on the order of 80–90 dB HL.

Case Study 3: Erroneous Hearing Loss

Case 3 continues to be a challenge in testing. It is becoming more and more obvious that this patient is not obeying the request to indicate when a signal is barely perceptible. This will be manifested in the same ways as it was for pure tones, probably resulting in a normal SRT for the right ear and no response to spondees in the left ear. As in the case of pure tones, this total absence of response from the left ear is prima facie evidence of erroneous hearing loss since a shadow response should have been observed at about 50 dB HL. This behavior, if the patient is consistent in his perseverance at convincing you that he is, in fact, deaf in his left ear, will result in no response on tests of SRS, MCL, or UCL. While the diagnosis of erroneous hearing loss is increasingly evident, the degree of hearing loss in the left ear, if any exists, is yet to be determined. More sophisticated tests will be necessary for this patient than have been described in this chapter but will be available in later chapters.

Case Study 4: Pediatric Patient

Since one of this child's problems is a delay in speech and language development and she is increasingly giving the impression that she has a severe hearing loss, it is unlikely that she will be able to participate in the tests described in Chapter 5. When working with children, it is almost always advisable to begin with the most adult-like procedures available and modify these as needed. The approach to speech audiometry for children described in Chapter 8 will probably have to be utilized in this case.

Summary

Speech audiometry includes measurement of a patient's thresholds for speech: speech-recognition threshold (SRT); speech-detection threshold (SDT); most comfortable loudness level (MCL); uncomfortable loudness level (UCL) or loudness discomfort level (LDL); range of comfortable loudness (RCL) or dynamic range (DR); and speech-recognition score (SRS) or word-recognition score (WRS). Measurements may be made either monaurally or binaurally under earphones, through a bone-conduction vibrator or in the sound field through loudspeakers. Materials for speech audiometry may include connected speech, two-syllable (spondaic) words, monosyllabic words, or sentences. The materials may be presented by means of a tape recorder, CD player, or

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AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐	RIGHT								LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000
Masking Type WB ☐ NB ☐	5	0	5	5	0	5	10	5	5	0	5	5	5	5	0	0	0	5
EM Level in Opp. Ear																		

BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT						FOREHEAD						LEFT					
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type WB ☐ NB ☐							0	5	5	5	5	0						
EM Level in Opp. Ear																		

Pure Tone Average	2 Freq	3 Freq	Variable	WEBER						2 Freq	3 Freq	Variable
	0	2	5	M	M	M	M	M	M	5	5	5

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☒	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
	0		List 1 1/3 HL 100%	List 2 3/4 HL 98%	5		List 1 2/3 HL 98%	List 2 3/4 HL 100%
EM Level in Opp. Ear				20				20

FREQUENCY IN HERTZ

HEARING LEVEL in dB
(ANSI - 1996)

Speech Presentation

SRT ☒ MLV Recorded ☐

WRS ☐ ☒

COMMENTS

AUDIOGRAM KEY

Right Left

AC Unmasked ○ ×

AC Masked □

BC Mastoid Unmasked △ >

BC Mastoid Masked ▽

BC Forehead Masked +

Both

BC Forehead Unmasked ↓

Sound Field (unaided) S

Sound Field (aided) s

Opp Ear Masked *

Examples of
No Response Symbols

○ ×

△ >

▽

FIGURE 5.5 Audiogram illustrating normal hearing in both ears. Note that the two- and three-frequency PTAs, as well as the variable PTA, compare favorably with the SRTs. The WRS in each ear is very high at both 30 dB SL and 90 dB HL. Masking is needed only for the high-level WRS test as will be discussed in Chapter 6.

microphone (using monitored live-voice). At times the sensitivity of the nontest ear by bone conduction is such that it may inadvertently participate in a test under earphones. When cross hearing is a danger, a masking noise must be presented to the nontest ear to eliminate its participation in the test. Details of this are explained in Chapter 6.

Measurements using speech audiometry augment the findings of pure-tone tests and help to determine the extent of a patient's hearing loss, loudness tolerance, and speech recognition. The knowledge gained from the use of speech audiometry is helpful in the diagnosis of the site of lesion in the auditory system, as well as in audiological treatment.

The audiograms depicted in Chapter 4 illustrating normal hearing, conductive hearing loss, and sensory/neural hearing loss are repeated in Figures 5.5, 5.6, and 5.7. These figures show the probable results obtained during speech audiometry, including the use of masking, where indicated.

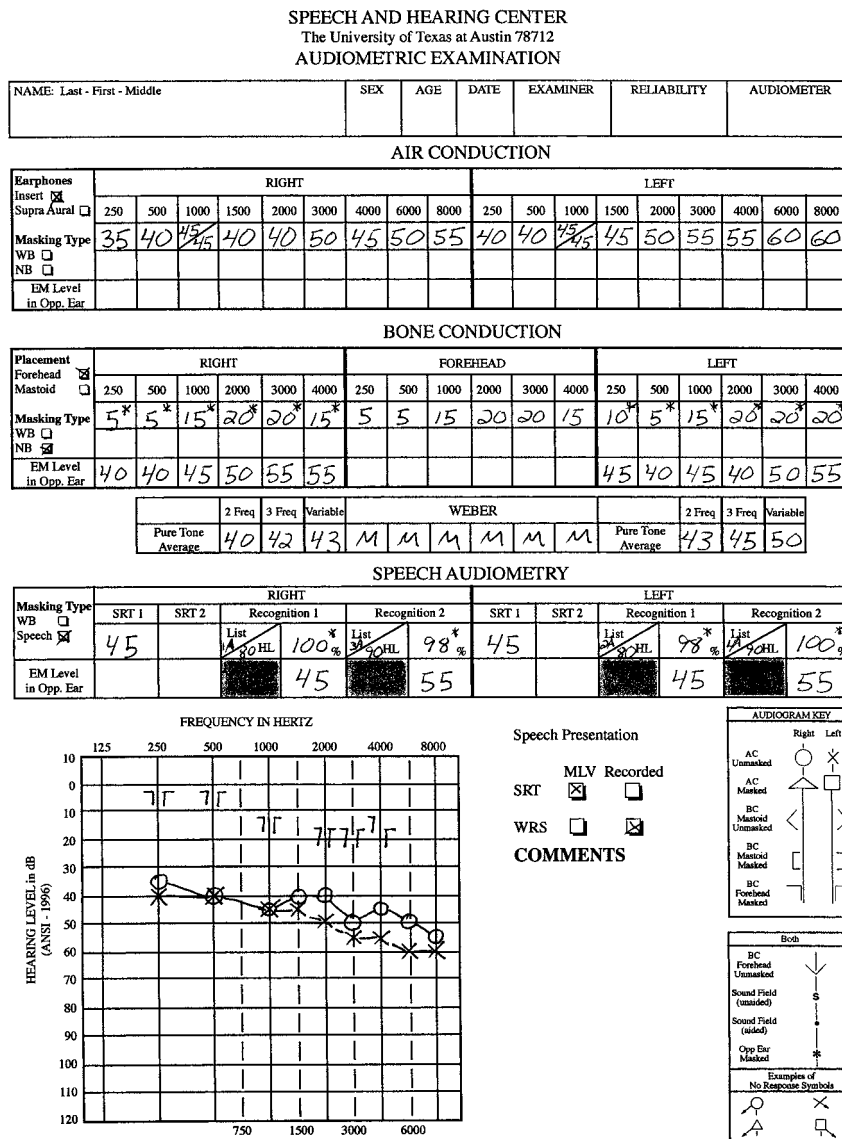


FIGURE 5.6 Audiogram illustrating conductive hearing loss in both ears. The PTAs are in close agreement with the SRTs. The WRSs are high in both ears, even at 90 dB HL. Masking was required for a number of the procedures used here and will be discussed in Chapter 6.

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AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐	RIGHT								LEFT								
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000
Masking Type	35	35	40	45	50	60	70	75	40	35	45	50	55	60	65	65	60
WB ☐																	
NB ☐																	
EM Level in Opp. Ear																	

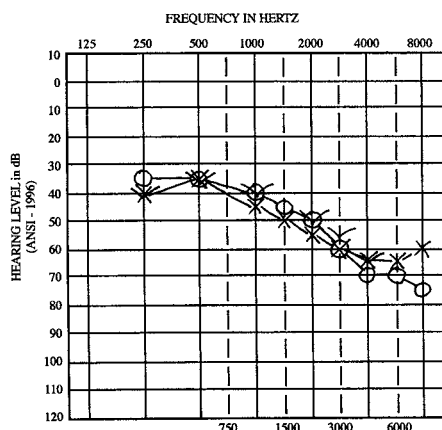
BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT				FOREHEAD				LEFT									
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type							40	35	40	50	55	65						
WB ☐																		
NB ☐																		
EM Level in Opp. Ear																		

	2 Freq	3 Freq	Variable	WEBER						2 Freq	3 Freq	Variable	
Pure Tone Average	38	42	53	M	M	M	M	M	M	Pure Tone Average	40	45	55

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☐	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
	35		List 1/65 HL 78 %	List 2/40 HL 76 %	40		List 1/70 HL 80 %	List 2/40 HL 82 %
EM Level in Opp. Ear								



Speech Presentation

MLV Recorded
 SRT ☒ ☐
 WRS ☐ ☒
 COMMENTS

AUDIOGRAM KEY

Right AC Unmasked AC Masked BC Masked BC Masked BC Forehead Masked	Left AC Unmasked AC Masked BC Masked BC Masked BC Forehead Masked

Both

BC Forehead Unmasked Sound Field (unaided) Sound Field (aided) Opp Ear Masked	Examples of No Response Symbols (Diagrams showing various symbols for no response)

FIGURE 5.7 Audiogram illustrating sensory/neural hearing loss in both ears. The two- and three-frequency pure-tone averages agree closely with the SRTs, but because the audiogram falls in the high frequencies, the SRTs are lower than the variable pure-tone averages. WRSs show some word-recognition difficulties in both ears.

REVIEW TABLE 5.1 Summary of Tests Used in Speech Audiometry

Test	Purpose	Material	Unit
SRT	HL for speech recognition Verify PTA	Spondees; Cold running speech	dB
SDT	HL for speech awareness	Cold running speech	dB
MCL	Comfort level for speech	Cold running speech	dB
UCL	Level at which speech becomes uncomfortably loud	Cold running speech	dB
RCL (DR)	Dynamic listening range for speech	Cold running speech	dB
SRS	Recognition of speech	PB words; CNC words; rhyming words; sentences	%

Study Questions

1. Sketch, from memory, performance-intensity functions for spondaic words and PB word lists. Explain the differences in the curves on the basis of the words used.
2. Sketch audiograms illustrating normal hearing, as well as conductive, sensory/neural, and mixed hearing losses. Predict the probable SRTs, SRSs, MCLs, UCLs, and RCLs.
3. What are the theoretical and practical values for the audiologist and for the speech-language pathologist of the measures obtained in question 2?
4. List the different kinds of tests described in this chapter and the different materials used for each test.
5. Look back at Figure 5.7. What would you expect speech-recognition performance to be at conversational intensities and why? What benefits are there for testing at this level?
6. Why might one want to compare monaural left and right speech-recognition scores to binaural speech-recognition performance?

Suggested Reading

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Endnote

1. Auditec of St. Louis (800-669-9065).

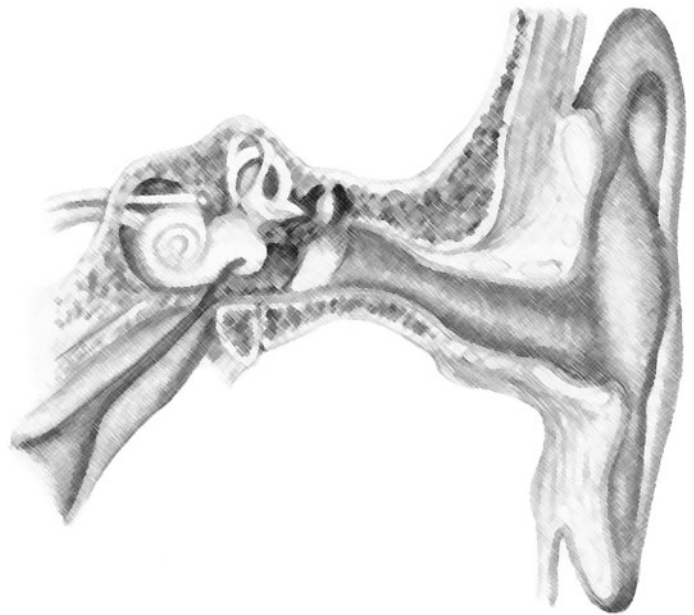
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CHAPTER 6



Masking

AS MOST PEOPLE KNOW, during vision testing one eye is covered to make certain that the uncovered eye is the one taking the test. This cover is called a mask. Unfortunately, this simple solution is not available when testing hearing because covering the ear opposite the one being tested not only does not eliminate it from participation but also, in the case of some bone-conduction tests, actually makes the sound louder in the nontest ear and increases its participation. For this reason, masking for auditory tests requires that a noise be introduced into the ear not being tested to raise its threshold so that it cannot respond to a signal presented to the test ear. This is auditory masking, and the need for its use and its application vary depending on the kind of test being performed.

LEARNING OBJECTIVES

This chapter describes the proper means of obtaining masked responses during audiometric testing when it is necessary to ensure that the patient does not respond to a signal received by the non-test ear. Upon completion of this chapter, the reader should be able to

- Understand the concepts of cross hearing.
- Understand when masking signals should be employed.
- Describe the differences in determining the need to mask when testing pure-tone air conduction, pure-tone bone conduction, speech-recognition thresholds, and speech-recognition scores.
- Discuss the different masking methods for the above tests.
- Understand why different noise spectra are used for speech and pure-tone tests.

Cross-Hearing in Air- and Bone-Conduction Audiometry

It is logical to assume that if hearing sensitivity is considerably better in one ear than in the other (say 50 dB to 70 dB), it is possible that before the threshold of the poorer ear is reached, the intensity of the signal may be sufficient for the sound to escape from beneath a supra-aural air-conduction earphone or around the edges of an insert earphone into the room and be heard by the better ear. Resultant audiograms plotted when this happens have been called “shadow-grams.” However, it is more common for louder sounds introduced by air conduction to actually cross from one side of the head to the other, primarily by bone conduction (Chaiklin, 1967; Martin & Blosser, 1970). It is probable that whenever the intensity is raised to a high enough level, the supra-aural air-conduction receiver or insert receiver vibrates sufficiently to cause deformations of the skull, giving rise to bone-conducted stimulation. If the level of a tone thus generated is above the bone-conduction threshold of the nontest ear, the patient will respond, signaling that the tone has been heard before the auditory threshold of the test ear has actually been reached, assuming the test ear has sufficient hearing loss.

As sounds travel from one side of the head to the other, a certain amount of energy is lost in transmission. This loss of intensity of a sound introduced to one ear and heard by the other is called **interaural attenuation (IA)**. Interaural attenuation for air conduction varies with frequency and from one individual to another. Results of three studies of interaural attenuation using two different kinds of earphones are shown in Table 6.1.

The danger of **cross hearing** for air-conducted tones presents itself whenever the level of the tone in the test ear (TE) by air conduction, minus the interaural attenuation (IA), is equal to or higher than the bone-conduction threshold of the nontest ear (NTE). Stated as a formula:

$$AC_{TE} - IA \geq BC_{NTE}$$

1. Cross hearing is less likely to occur when insert earphones are used because the _____ is increased.

Since it is not possible to know in advance the interaural attenuation of a given patient, it is advisable to adopt a conservative approach and consider 40 dB to be the minimum possible value when using supra-aural audiometer earphones. Since insert earphones provide more interaural attenuation than supra-aural phones, 70 dB can be substituted for 40 dB in the formula, meaning that masking will be required much less frequently when using insert phones.

Because there is rarely a way of knowing for certain which cochlea has been stimulated by a bone-conducted tone regardless of where the vibrator is placed, cross hearing during bone-conduction tests is always a possibility. Therefore, the minimum IA for bone conduction should,

TABLE 6.1 Minimum Interaural attenuation for pure tones using supra-aural earphones according to (A) Coles and Priede (1968), (B) Zwislacki (1950), (C) Sklare and Denenberg (1987)

Frequency in Hz	Interaural Attenuation		
	A-Supra-Aural Earphones	B- Supra-Aural Earphones	C-Insert Earphones
250	61	45	89+
500	63	50	94+
1000	63	55	81
2000	63	60	71
4000	68	65	77

for clinical purposes, be considered to be 0 dB. There are many approaches to dealing with the problem of cross hearing, only one of which is discussed in this book

From a practical clinical viewpoint, it seems important to ask, “Does it matter which ear has responded during pure-tone audiometry?” In the case of air conduction, the answer is an emphatic “yes,” for one must know for certain the hearing sensitivity of each ear. In the case of bone conduction, as illustrated in Figures 4.13 (conductive loss) (see page 92) and 4.15 (mixed loss) (see page 94), the answer is also yes because the bone-conducted thresholds of each ear tell the amount of conductive involvement (by comparing them to air conduction) and the amount of sensory/neural involvement (by comparing them to 0 dB HL). If a bone-conduction response is obtained from the nontest ear, a completely incorrect diagnosis of the test ear may result. In

the case of Figure 4.14 (page 93), however, it really does not matter which ear has responded to the bone-conduction signal because both ears show an absent air-bone gap, resulting in a diagnosis of bilateral sensory/neural hearing loss. Therefore, cross hearing in bone-conduction testing is of concern only when there is an air-bone gap in the test ear.

2. During audiometry
cross hearing occurs by

Masking

Whenever cross hearing is suspected, it is necessary to eliminate the nontest ear from the procedure to determine (1) whether the original responses were obtained through the nontest ear and, (2) if they were, what the true threshold of the test ear really is. The only way to accomplish masking for auditory signals is to deliver a noise to the nontest ear to raise its threshold, thereby removing it from the test.

ASHA’s (2005) most recent guidelines recommend that masking be used during bone conduction testing if the bone-conduction threshold is better (lower) than the air-conduction threshold by 10 dB or more in the same ear. However, since there is a certain amount of normal variability between air- and bone-conduction thresholds, even among patients without conductive hearing losses, bone-conduction thresholds often appear to be slightly better (or even sometimes slightly poorer) than air-conduction thresholds. It seems practical, therefore, to consider air-bone gaps up to 10 dB to be insignificant. Thus, cross hearing for bone conduction should be suspected whenever an air-bone gap *greater* than 10 dB is seen in the test ear:

$$ABG_{TE} > 10 \text{ dB}$$

Clinical Commentary

Masking must be undertaken whenever there is a possibility that unmasked test results may be derived from the nontest ear. In other words, one must mask whenever the use of masking may change the diagnosis of the type and/or degree of hearing loss at any frequency in either ear. After the air-conduction thresholds have been obtained, with proper masking when appropriate, the relationship between the thresholds by bone conduction and air conduction (the air-bone gap, the conductive component of the hearing loss) and between bone-conduction thresholds and normal hearing levels (the actual degree of sensory/neural hearing loss), become of paramount importance.

TABLE 6.2 Effects of Masking the Nontest Ear on the Diagnosis of True Bone-Conduction Thresholds

	<i>Air Conduction</i>	<i>Bone Conduction</i>	<i>Air-Bone Gap</i>	<i>Might Masking Change the Diagnosis?</i>
Normal	10	5	5	No
Sensory/Neural	35	30	5	No
Conductive	35	5	30	Yes
Mixed	60	35	25	Yes

Many audiologists claim that since they usually cannot be certain which ear has responded, they mask routinely for all bone-conduction tests (Martin, Champlin, & Chambers, 1998). This can be extremely time consuming and is often unnecessary and unpleasant for the patient. Other clinicians use interaural attenuation values, like 10 dB, to determine the possibility of cross hearing, but that is a *passé* notion since, as stated above, it must be assumed that there is no interaural attenuation for bone conduction.

The important question to ask is whether masking for bone conduction might result in a change in diagnosis from unmasked values. Using Table 6.2 as an example, four usual audiometric findings are demonstrated in terms of air-bone relationships in the same ear at any given frequency. What must be remembered is that while masking may result in responses for bone-conduction thresholds remaining unchanged from unmasked values or may result in responses for bone-conduction thresholds becoming worse (poorer hearing), masking the nontest ear cannot cause thresholds to appear better.

In the examples in Table 6.2 the similarity between normal hearing and sensory/neural hearing loss is that they both exhibit no significant air-bone gap; that is, there is no meaningful conductive component at the frequency tested. Therefore, opposite ear masking will either leave the threshold results unchanged or make them appear poorer than air conduction. The conclusion that can be drawn from this is that masking cannot change the diagnosis in either of these cases, so there is no need to mask.

Conductive and mixed hearing losses, as can be seen in Table 6.2, have in common that they both exhibit air-bone gaps; that is, there is some conductive component to the hearing loss. In either case, if the bone-conduction thresholds become poorer with masking, indicating that the initial results were obtained from the nontest ear, the diagnosis can change dramatically. In such cases, masking may reveal that either of those cases that appear to have conductive components may actually be sensory/neural, or the sensory/neural portion of the loss may be greater than what appeared without masking.

The alert audiologist will probably suspect the possibility of cross hearing more often than it actually occurs. This is good, for it is better to mask unnecessarily than to fail to mask when a signal has been heard in the nontest ear. In clinical audiology the rule should be “When in doubt, mask.”

Clinical Commentary

Some experienced clinicians have noted that if mastoid bone-conduction testing is done, there is really no need to test from the second mastoid for those frequencies in which no air-bone gaps are observed. Air-conduction thresholds for both ears must, of course, be compared to the mastoid bone-conduction results. A notation must be made so that an interpreter of audiometric results will not believe that the second ear was not tested by bone conduction due to an oversight.

If a split audiogram is used, there is no need to post the unmasked forehead bone-conduction responses on both audiograms. Air-conduction thresholds for both ears must be compared to forehead results at all frequencies to show the lack of air-bone gaps and therefore that there is no need to mask. A written comment should be added to make this apparent.

Noises Used in Pure-Tone Masking

The relative effectiveness of a noise in masking a pure tone is determined by several variables, including the spectrum of the noise, how the masking-level dial is calibrated, and the kind of earphone used to deliver the noise to the masked ear. When these variables are understood and controlled, the task of masking becomes considerably easier.

Several different kinds of masking noises are available on commercial pure-tone audiometers. Each noise has a characteristic spectrum and therefore provides a different degree of masking efficiency at different frequencies.

It is possible to generate a noise that has approximately equal energy per cycle and covers a relatively broad range of frequencies. Because of this analogy to white light, which contains all the frequencies in the light spectrum, this signal has been called **white noise**. White noise, which has also been called thermal and Gaussian¹ noise, sounds very much like hissing. Since the earphones accompanying many audiometers are not of very high quality, they do not provide much response in the higher frequencies and therefore limit the intensity of white noise above about 6000 Hz. Hence, that which is labeled on the audiometer as white noise is more accurately termed broadband or wideband noise, because it emanates from the earphone.

Because it has been proven that the masking of a pure tone is most efficiently accomplished by frequencies immediately surrounding that tone, the additional frequencies used in a broadband noise are redundant. They supply additional sound pressure and loudness to the patient, with no increase in masking effectiveness. Through the use of band-pass filters it is possible to shape the spectrum of a broadband noise into **narrowband noise**. Modern digital technology now allows the generation of a digital noise that can be of any desired bandwidth and contain only the desired frequencies.

Surrounding every pure tone is a **critical band** of frequencies that provides **maximum masking** with minimum sound pressure. Narrowing the noise band to less than the critical bandwidth requires greater intensity to mask a given level of tone. Conversely, adding frequencies outside the critical band increases intensity (and therefore loudness) without increasing masking effectiveness. The narrow noise bands found in most audiometers are usually considerably wider than the critical band.

The earphones still frequently employed to deliver a masking noise during clinical pure-tone testing are the ones provided with most audiometers, the TDH-39, TDH-49, or TDH-50P earphones, with MX-41/AR (supra-aural) cushions. There are many reasons to prefer the use of insert earphones, which decrease the occlusion effect evident in bone conduction when an ear is covered (Dean & Martin, 2000) and therefore have an advantage in masking during bone-conduction testing. In addition, because they are coupled to a smaller area of the skull, insert receivers provide 70 to 100 dB of interaural attenuation. When the foam rubber surrounding the tubing at the end of an insert receiver is inserted deeply into the external ear, an additional 15 to 20 dB of interaural attenuation can be achieved (Killion, Wilber, & Gudmundsen, 1985).

Calibration of Pure-Tone Masking Noises

Calibration of the masking noise of an audiometer requires that the linearity of the masking-level dial be accurate and that the intensity reference be known. Linearity calibration is best accomplished through the use of a device called an **electronic voltmeter**, which measures differences in decibels. By making measurements at the terminals of the earphones, the hearing-level dial can be moved in steps of 5 dB, and the accuracy of this 5 dB change can be checked throughout the entire range of the attenuator (–10 to 110 dB HL).

Surveys have shown that it is common practice for the decibel reference for masking to be in either sound-pressure level or hearing level. However, the concept of **effective masking (EM)** for clinical testing is very practical and easy to use once the audiometer has been properly calibrated. Effective masking may be defined as the minimum amount of noise required to make a given signal inaudible. Thus, 20 dB EM at 1000 Hz is just enough noise to make a 20 dB HL 1000 Hz tone inaudible; 50 dB EM would just mask out a 50 dB HL tone, and so on. In the presence of 50 dB EM, a tone will not become audible until it reaches approximately 55 dB HL, regardless of an individual's hearing loss (assuming the hearing loss is less than 55 dB). This is true because any hearing loss attenuates both the tone and the masking noise equally and because it assumes that the signal and the masker are both being heard *in the same ear*.

The calibration of a noise in units of effective masking can be carried out using about a dozen normal-hearing subjects as follows:

1. Present a 1000 Hz tone at 30 dB HL to one ear by air conduction. Pulse the tone on and off to minimize auditory fatigue.
2. Present a noise (preferably narrowband) to the same ear.
3. Raise the level of the noise in 5 dB steps until the 30 dB tone is no longer audible. The tone should be heard again at about 35 dB HL. Recheck several times for accuracy.
4. Take a mean value of the masking-level dial setting at which the 30 dB HL tone was just barely masked. Round this number out to the closest multiple of 5 dB.
5. Add 10 dB as a safety factor to offset the normal dispersion seen around any mean. This is 30 dB EM at 1000 Hz.
6. Subtract 30 dB from the above value. This is 0 dB EM at 1000 Hz.
7. Repeat this procedure for all audiometric frequencies.
8. Post a correction chart on the audiometer showing the number of decibels that must be added to the hearing-level dial reading to reach 0 dB EM for each frequency.

A worksheet for determining effective masking is shown in Figure 6.1. For an example of how effective masking works, see Table 6.3.

Once calibration has been completed, any level at any frequency can be masked (in the same ear) up to the maximum masking limits of the audiometer simply by adding the determined correction factor to the threshold level of the ear to be masked. If, as in the example above, a +25 dB correction is needed for 0 dB EM, and a 40 dB tone is to be masked, the masking-level dial would be set to 40 dB EM, which is actually 65 dB HL (40 dB for the tone to be masked plus a 25 dB correction, which includes the safety factor). The safety factor is therefore built into the correction, and it should not be added again when determining the need for individual masking levels.

Of course, when masking is done clinically, the masker is presented to the earphone *opposite* the test earphone. Using this procedure assumes that the test tone may have lateralized and is actually heard in the masked ear. Therefore, if the tone has indeed lateralized, introduction of an EM level into the nontest ear (equal to the threshold of the nontest [masked] ear plus the predetermined correction factor, which includes the safety factor) should render the tone

A	HL of Signal	30	30	30	30	30	30	30	30	30	30	30	30
B	Mean Noise Level												
C	Rounded to Multiple of 5												
D	Safety Factor												
E	Correction Factor (C + D)												
F	Subtract 30												
G	This is 0 dB EM (E - A)												
	Subject	125	250	500	750	1000	1500	2000	3000	4000	6000	8000	Speech
	1												
	2												
	3												
	4												
	5												
	6												
	7												
	8												
	9												
	10												
	11												
	12												

FIGURE 6.1 Form for determination of 0 dB of effective masking (EM) for pure tones and speech using a group of subjects with normal hearing. The following operations should be carried out for each column and the results from Row G posted on the audiometer.

- Present the signal and noise to the same ear at 30 dB HL for each frequency and for spondaic words.
- Vary the intensity of the noise until the signal is barely masked out. Record the result in the appropriate cells for each subject in the desired columns. Record the mean value for each column at the top of the form in Row B.
- Round the numbers in Row B to the closest multiple of 5 dB.
- Add a safety factor of 10 dB to the numbers in Row C.
- This is 30 dB EM (C + D).
- Subtract 30 dB from Row E.
- This is 0 dB EM (E - A). When masking during clinical tests, this value must be added to the threshold of the nontest ear to attain the initial EM for that threshold value.

inaudible. At this point the masking plateau process (to be described under *masking methods*) may begin. If the tone has not lateralized, introduction of that same level of masking into the nontest ear will allow the tone to remain audible (as it is still being heard in the test ear), and the masking exercise is complete for the frequency tested.

TABLE 6.3 Example of Effective Masking (units are in decibels)
Assume that the average for a dozen normal-hearing subjects shows that at 1000 Hz a 30 dB HL tone is barely masked with a 45 dB HL masking noise.

1	2	3	4	5	6	7
Hearing Level of Tone	Hearing Level of Noise in Same Ear to Just Mask Out Tone	Difference	Safety Factor	Correction Factor to Be Applied to Reach 30 dB Effective Masking	Masking-Level Dial Reading for this Effective Masking Level	Effective Masking
30	45	15	10	+25	55	30
20	35	15	10	+25	45	20
10	25	15	10	+25	35	10
0	15	15	10	+25	25	0

Another example of the above follows. Assume that a patient's thresholds (using insert ear-phones) are as follows:

Right ear AC 20 dB HL
Right ear BC 10 dB HL
Left ear AC 80 dB HL

The criteria are met to mask the right (nontest) ear and retest the left (test) ear with masking in the right since cross hearing may have occurred ($80 \text{ dB [test ear AC]} - 70 \text{ dB [IA]} = 10 \text{ dB HL [nontest ear BC]}$).

The initial masking level would be 20 dB EM. The hearing-level dial to achieve 20 dB EM would be 45 dB HL, which is the threshold of the ear to be masked [20 dB HL] plus the predetermined correction factor of 25 dB, which includes the 10 dB safety factor.

Central Masking

Over 85 years ago, Wegel and Lane (1924) showed that a small shift is seen in the threshold of a pure tone when a masking noise is introduced to the opposite ear. This threshold shift increases slightly with increased noise but averages about 5 dB. It is believed that the elevation of threshold is produced by inhibition that is sent down from the auditory centers in the brain and has, therefore, been called **central masking**. Central masking must be differentiated from **overmasking (OM)**, in which the noise is actually so intense in the masked ear that it crosses the skull and produces masking in the test ear.

Masking Methods for Air Conduction

Masking must be undertaken whenever the possibility of cross hearing in air conduction exists. A survey of clinical audiologists on contemporary clinical practices (Martin et al., 1998) showed more disagreement on masking methods, and apparently greater insecurity, than on any other clinical procedure.

The "Shotgun" Approach. It is possible, in a large number of cases, for clinicians to mask by using some fixed or arbitrary level of noise in the masked ear, without really understanding what they are doing. In uncomplicated cases the masking procedure often appears to be satisfactory. Because of insufficient feedback about their errors, some individuals fail to profit from their mistakes and continue with such erroneous philosophies as "Just use 70 dB of noise," with no recognition of the properties of the noise or of its effectiveness. Clinicians may be unaware of when they have used too little or too much masking noise.

The Minimum-Noise Method. Through calibration, it is possible to determine the minimum amount of noise necessary to mask a pure tone at a given intensity. There is no need to burden the patient with any more noise than is necessary to get the job done. As discussed earlier, the best way to do this is to regard the noise level in terms of decibels of effective masking.

Several time-consuming, and frequently clinically impractical, formulas have been developed over the years for the determination of the minimum and maximum amounts of effective masking to be used. Martin (1974) has shown that the different formula approaches yield the same noise sound-pressure levels as does a simple, direct approach, requiring almost no calculation. This simple approach is described in the following paragraph.

When test results suggest the possibility of cross hearing, they should be examined closely. Consider the example in Figure 6.2. The criteria for masking are met for the left ear by air conduction, assuming the use of supra-aural earphones, since the threshold (60 dB HL) minus minimal IA (40 dB) is greater than the bone-conduction threshold of the right ear (10 dB HL). It is known, since the test was presumably performed carefully, that the 60 dB response was a threshold. However, the question that arises is “The threshold of which ear?” If the right (nontest) ear can be removed from the test by masking, and the threshold of the left (test) ear remains unchanged, this means that the original response was obtained through the test ear. If, however, eliminating the right ear from the test results in a failure of response at the left ear at the previous level (plus 5 dB for central masking), the right ear provided the hearing for the original response and further masking is required to determine the true threshold of the left ear. It should be noted in this example that, had insert receivers been used, the entire issue of masking would have been averted.

The minimum amount of noise required for the screening described is an effective masking level equal to the AC threshold of the nontest ear plus the predetermined correction factor, and may be referred to as **initial masking (IM)**. This is just enough noise to shift the threshold of that ear 5 dB, by both air conduction and bone conduction. If the threshold of the tone presented to the test ear was originally heard by bone conduction in the nontest ear, raising the bone-conduction threshold of the nontest ear with masking will eliminate the possibility of this response.

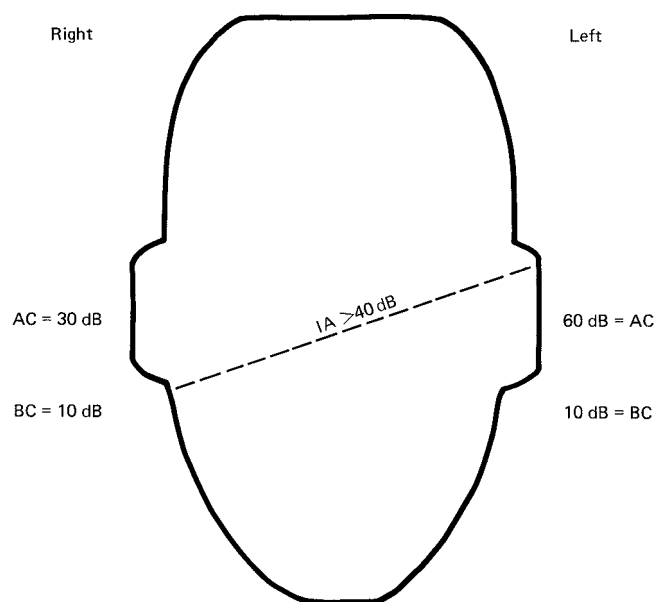


FIGURE 6.2 Illustration of the need to mask during air-conduction tests. Because the difference between the left-ear air-conduction threshold (60 dB HL) and the right-ear bone-conduction threshold (10 dB HL) exceeds the minimum possible interaural attenuation (40 dB), cross-hearing is a possibility. Note that the minimum interaural attenuation for this patient must be 50 dB (AC left minus BC right). Masking needed for the right ear is 30 dB EM.

Maximum Masking

Just as a tone can lateralize from test ear to nontest ear, given sufficient intensity, so can the masking noise lateralize from masked ear to test ear, both by bone conduction. An individual's interaural attenuation cannot be less than the difference between the air-conduction level in the test ear and the bone-conduction level in the nontest ear at which threshold responses are obtained. For example, even though Figure 6.2 does not illustrate cross hearing *per se*, but rather the possibility of cross hearing, the interaural attenuation for the individual illustrated cannot be less than 50 dB for the test frequency (air-conduction threshold of the test ear minus bone-conduction threshold of the nontest ear).

Whenever the level of effective masking presented to the masked ear, minus the patient's interaural attenuation, is above the bone-conduction threshold of the test ear, a sufficient amount of noise is delivered to the cochlea of the test ear to elevate its threshold. This is overmasking (Figure 6.3). The equation for overmasking for pure tones is

$$EM_{NTE} \geq BC_{TE} + IA$$

Maximum masking is equal to the threshold of the test ear by bone conduction plus the interaural attenuation, minus 5 dB. When ears with large air-bone gaps are tested, minimum masking quickly becomes overmasking, sometimes making determination of masked pure-tone thresholds difficult. In such cases audiologists must recognize the problem and rely on other tests and observations to make their diagnoses.

The Plateau Method

This book presents a modification of a popular masking method first reported more than half a century ago (Hood, 1960). By combining Hood's plateau method with the minimum-noise method, one begins with the initial masking level (the air-conduction threshold of the masked ear plus the predetermined correction factor). If the tone is no longer audible, the threshold for

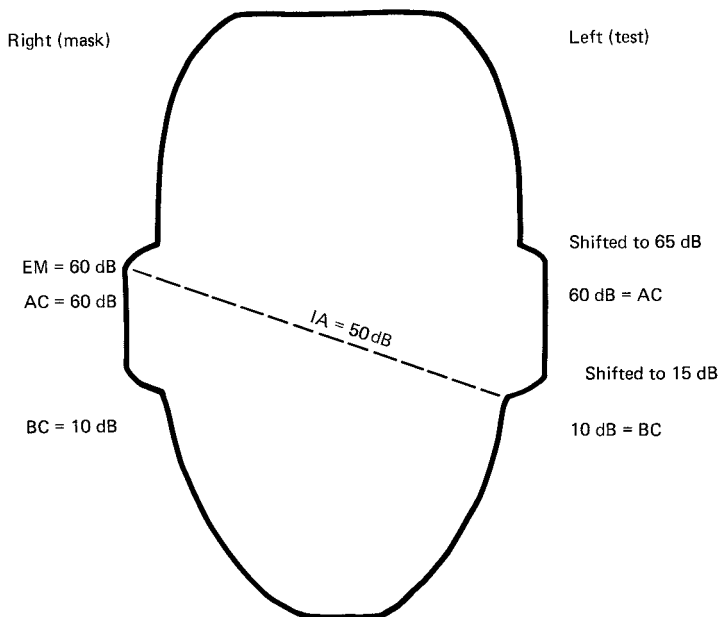


FIGURE 6.3 Example of overmasking. The effective masking level in the right ear (60 dB) is decreased by the interaural attenuation (50 dB) so that 10 dB EM is received by bone conduction in the left ear. This shifts the bone-conduction threshold to 15 dB, plus any additional shift for central masking. Adding more noise to the right ear results in increased masking at the left ear, with further threshold shifts. In this case the minimum amount of noise required to mask out the right ear produces overmasking.

the tone is measured again in the presence of the contralateral masking noise. The noise level is then increased 5 dB, and the threshold is measured again. This often results in necessary increases in the tone level of 5 dB for every 5 dB increase in noise in order to keep the tone audible. The assumption is that the threshold of the tone in the test ear has not been reached (**undermasking**), and that both tone and noise are heard by the nontest ear (Figure 6.4A). When the threshold of the tone for the test ear has been reached (Figure 6.4B), the level of noise can be increased several times without affecting the level of tone that evokes a response. This is the **plateau**. If the noise level is raised beyond a certain point (the bone-conduction threshold of the test ear plus the interaural attenuation), overmasking takes place and the tone and noise are mixed in the test ear. Further increases in noise will result in further shifts in the threshold of the tone (Figure 6.4C). Minimum and maximum masking are shown in Figures 6.4D and 6.4E.

3. During plateau seeking when the signal and masker are both heard in the test ear, _____ has taken place.

Problems of overmasking plague all the masking methods, including the plateau system, whenever there are large air-bone gaps in both ears. The larger the air-bone gap, the narrower the plateau; the smaller the air-bone gap, the broader the plateau.

The width of the masking plateau is determined by three variables: (1) the air-conduction threshold of the nontest (masked) ear, (2) the bone-conduction threshold of the test ear, and (3) the patient's interaural attenuation. The higher the air-conduction threshold of the masked ear, the greater must be the initial masking level; the higher that level is,

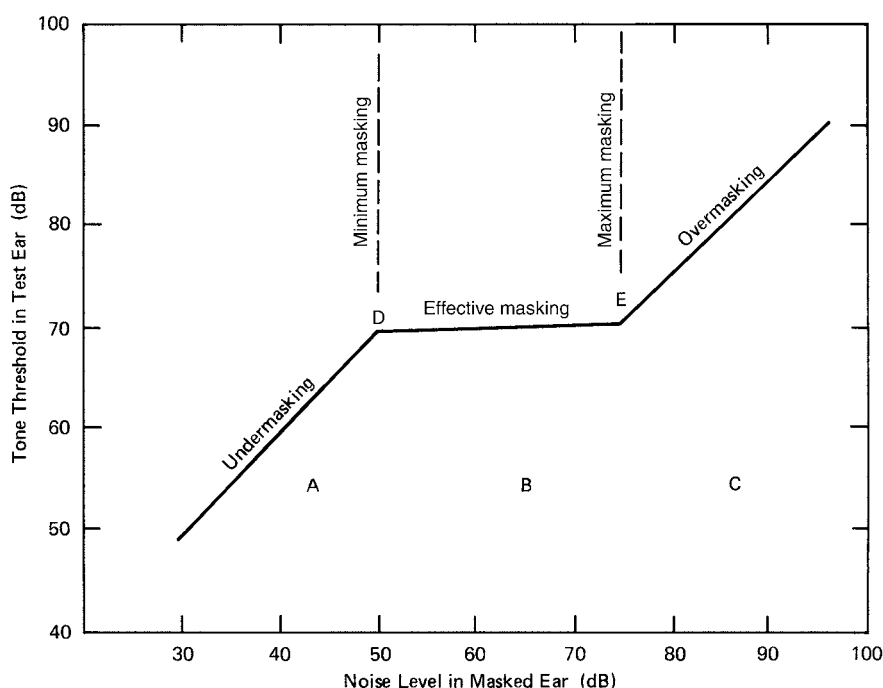


FIGURE 6.4 The plateau method for masking. (A) Undermasking: The tone (by cross hearing) continues to be heard in the masked ear despite the noise, since the tone level is below the threshold of the test ear. (B) The plateau: The tone has reached the threshold of the test ear. Therefore, raising the masking level in the masked ear does not shift the threshold of the tone. (C) Overmasking: The masking level is so intense that it crosses to the test ear, resulting in continuous shifts in the threshold of the tone with increases in the masking noise. Minimum (D) and maximum (E) masking are found at either side of the plateau.

TABLE 6.4 Factors That Influence the Width of the Masking Plateau

<i>Factor</i>	<i>Narrow Plateau</i>	<i>Wide Plateau</i>
AC threshold of masked ear	Higher	Lower
BC threshold of test ear	Lower	Higher
Interaural attenuation	Smaller	Larger

the greater are the chances that the noise will cross to the test ear. The lower the bone-conduction threshold of the test ear, the greater is the likelihood that a noise reaching the cochlea of that ear from a masking receiver on or in the opposite ear will exceed its threshold, producing a threshold shift in the test ear. The smaller the interaural attenuation, the higher the level of the noise that reaches the test ear. By increasing interaural attenuation from the test ear to the nontest ear as well as from the nontest ear to the test ear, insert receivers decrease the chances of overmasking and widen the masking plateau. These concepts are summarized in Table 6.4.

Clinical Commentary

The significantly higher interaural attenuation (IA) with insert receivers makes masking considerably easier for the audiologist for two reasons. First, the need for masking is eliminated in many instances because the value for IA is placed at 70 dB in the formula that determines if masking is needed ($AC_{TE} - IA \geq BC_{NTE}$). Second, when masking is required, the chances of overmasking are greatly reduced because of the greater IA.

Masking Methods for Bone Conduction

Masking methods for bone conduction are very much the same as for air conduction, and their success depends on the training, interests, and motivation of the clinician. One problem in masking for bone conduction that does not arise for air conduction is the method of delivery of the masking noise. The matter is simple during air-conduction audiometry, as both ears have earphones already positioned, and one phone can deliver the tone while the other phone delivers the masking noise. Because both ears are uncovered during bone-conduction testing, an earphone must be placed into or over the nontest ear without covering the test ear. The test ear must not be covered because this may cause an occlusion effect and alter the zero reference for bone conduction. Figure 6.5 shows the proper positioning of supra-aural receivers (A) and insert receivers (B) for masking during bone conduction, with the vibrator on the mastoid and also on the forehead.

When an earphone is placed over the nontest ear, an occlusion effect may be created in that ear. This means that the intensity of any cross-heard tones in the low frequencies is actually increased in the nontest ear, increasing the likelihood that the nontest ear will respond. Of course, if the masked ear has a conductive hearing loss, no additional occlusion effect is evidenced, but it is not always possible to know whether there is a conductive component in the masked ear.

Because the masking earphone may make the bone-conducted tone appear louder in the masked ear, the initial effective masking level must be increased by the amount of the occlusion effect. Failure to do this will result in undermasking in a significant number of cases.

The initial effective level for bone-conduction masking is the air-conduction threshold of the tone in the masked ear, plus the predetermined correction factor (CF), plus the occlusion effect (OE) for the tested frequency and can be expressed as

$$EM = AC_{NTE} + CF + OE$$

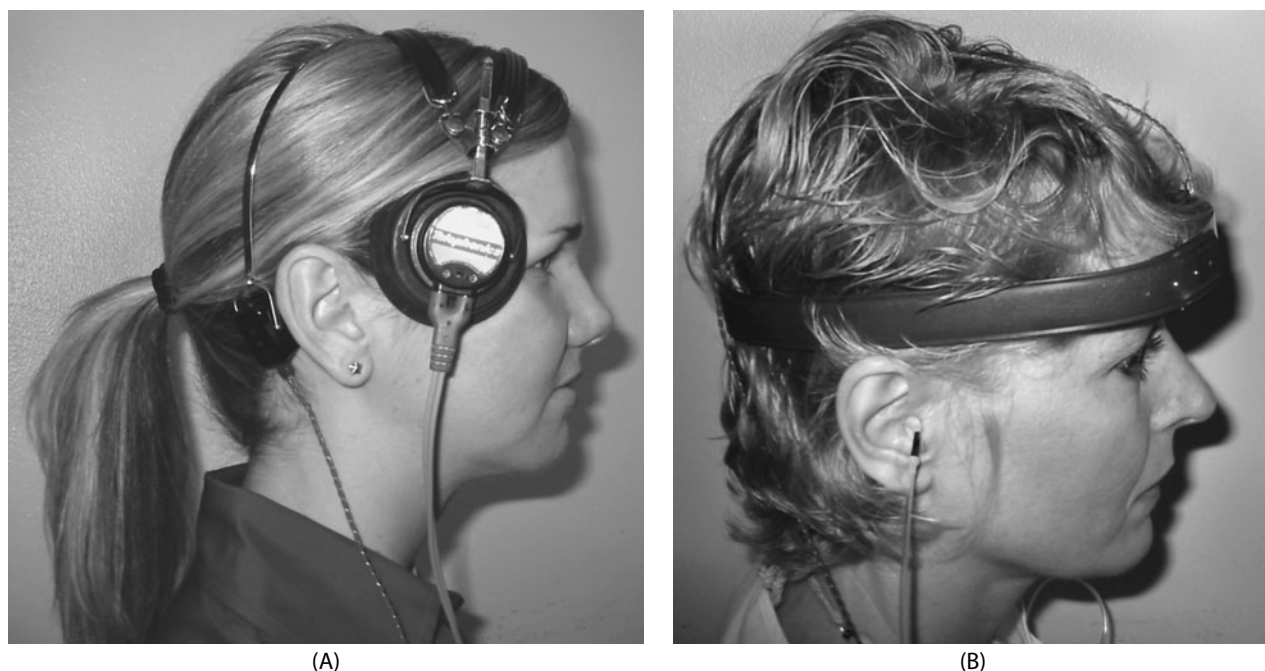


FIGURE 6.5 Masking noise delivered to the nontest ear during bone-conduction audiometry performed from (A) the mastoid, using a supra-aural earphone, and (B) the forehead, using an insert earphone.

This increased amount of noise raises the chance of overmasking. In many cases it is advantageous to use insert receivers to deliver the masking noise because less noise needs to be delivered to offset the smaller occlusion effect. The increased interaural attenuation provided by these small phones further decreases the probability of overmasking.

4. When masking for bone conduction, the patient's _____ must be added to the air-conduction threshold of the masked ear.

Martin, Butler, and Burns (1974) suggest a method by which the occlusion effect of the patient's masked ear may be determined and added to the initial masking level for air conduction. The procedure takes only moments and requires, after the need to mask for bone conduction has been determined, an audiometric version of the Bing tuning-fork test (described in Chapter 2). After the patient's unoccluded bone-conduction thresholds have been measured, the masking receiver is placed into or over the ear to be masked (no noise is presented). With the nontest ear occluded, the thresholds at 250, 500, and 1000 Hz are redetermined. The occluded thresholds for each frequency are subtracted from the unoccluded thresholds. The difference is the patient's own occlusion effect. These differences should be added to the initial masking levels determined for air conduction. The bone-conduction vibrator may be placed either on the forehead or on the mastoid.

Use of the audiometric Bing test results in little or no additional masking for conductive losses, where higher noise levels increase the danger of overmasking. When increased masking is required to offset the effect of having occluded the masked ear, the precise amount of noise may be added rather than some average figure that may be more or less masking than required for the individual patient.

The form shown in Figure 6.6 is useful when performing the audiometric Bing test. The recorded results provide quantitative information about the amount of occlusion effect for each

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Name: Last-First-Middle	Sex	Age	Examiner	Reliability	Date															
AUDIOMETRIC BING TEST																				
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 15%;"></th> <th colspan="3" style="width: 45%; text-align: center;">RIGHT</th> <th colspan="3" style="width: 40%; text-align: center;">LEFT</th> </tr> <tr> <th style="text-align: left;">Frequency (Hertz)</th> <th style="text-align: center;">250</th> <th style="text-align: center;">500</th> <th style="text-align: center;">1000</th> <th style="text-align: center;">250</th> <th style="text-align: center;">500</th> <th style="text-align: center;">1000</th> </tr> </thead> </table>								RIGHT			LEFT			Frequency (Hertz)	250	500	1000	250	500	1000
	RIGHT			LEFT																
Frequency (Hertz)	250	500	1000	250	500	1000														
1) Unoccluded																				
2) Occluded																				
3) Occlusion Effect (1-2)																				

FIGURE 6.6 Form for recording data obtained on the audiometric Bing test.

ear to be added to the initial effective masking level. In addition, the audiometric Bing test can be interpreted in the same way as the original tuning-fork test to assist in the diagnosis of conductive versus sensory/neural hearing loss.

Plotting Masked Results on the Audiogram

Before any threshold data are entered on the audiometric worksheet for either air conduction or bone conduction, 5 dB may be subtracted from the values obtained with the nontest ear masked to compensate for central masking, assuming the originally measured threshold shifted when masking was introduced. The appropriate symbols to indicate air conduction or bone conduction with and without masking are shown on the audiogram. The graph should contain only symbols that represent accurate thresholds; otherwise, the audiogram will appear cluttered and misleading. The plotting of contralateral responses is unnecessary, since they can readily be seen by examining the numerical insertions at the top of the audiometric worksheet. Whenever the nontest ear is masked for pure-tone air- or bone-conduction testing, the level of effective masking should be indicated on the audiometric worksheet. In this way, if someone other than the examiner should review the test results, the precise effective masking level that was used in testing can be seen.

Figure 6.7 illustrates a case of normal hearing in the right ear with a sensory/neural hearing loss in the left ear. Note that the original unplotted test results recorded in the boxes suggested that the hearing loss in the left ear was conductive. The air-bone gaps in the left ear were closed when proper masking was applied to the right ear indicating a sensory/neural hearing loss.

Clinical Commentary

As will be discussed later in Chapter 7, results of immittance testing in the above example would have ruled out the possibility of a conductive component in the left ear without the need for bone-conduction testing.

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AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐ Masking Type WB ☐ NB ☐ EM Level in Opp. Ear	RIGHT								LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000
	5	0	0	5	5	15	15	10	10	30	35	35	40	40	45	55	50	45

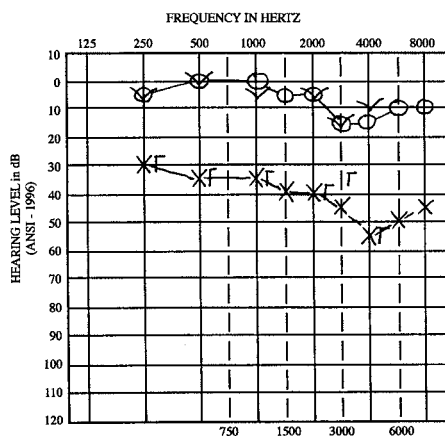
BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐ Masking Type WB ☐ NB ☒ EM Level in Opp. Ear	RIGHT				FOREHEAD				LEFT									
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
							5	0	5	5	15	10	30	35	35	40	35	55
													55	50	40	50	45	65

	2 Freq	3 Freq	Variable	WEBER				2 Freq	3 Freq	Variable	
Pure Tone Average	0	2	7	R	R	R	R	R	35	37	43

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☐ EM Level in Opp. Ear	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
			List HL	%			List HL	%



Speech Presentation

MLV Recorded

SRT ☐ ☐

WRS ☐ ☐

COMMENTS

AUDIOGRAM KEY	
Right	Left
AC Unmasked	○
AC Masked	△
BC Mastoid Unmasked	<
BC Mastoid Masked	>
BC Forehead Masked	□

Both	
BC Forehead Unmasked	▽
Sound Field (unaided)	•
Sound Field (aided)	•
Opp Ear Masked	*
Examples of No Response Symbols	
○	×
△	□

FIGURE 6.7 Audiogram showing normal hearing in the right ear and a sensory/neural hearing loss in the left ear. The original (unmasked) results by air conduction and bone conduction suggested a conductive hearing loss in the left ear because of the air-bone gaps. When proper masking was administered to the right ear, the bone-conduction thresholds shifted, proving absence of any air-bone gaps in the left ear. Tones on the Weber test lateralize to the better-hearing right ear.

The unmasked results shown in Figure 6.8 suggest a conductive loss in both ears, with poorer hearing by air conduction in the right ear. Using the criteria described earlier, masking was indicated for the right ear for air conduction and for both ears for bone conduction. Notice that the hearing loss in the left ear remains unchanged with masking, but the right ear actually has a severe mixed loss.

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AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☐ Supra Aural ☒	RIGHT									LEFT								
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000
Masking Type WB ☐ NB ☒	50	55	45	50	55	65	70	70	75	45	40	45	45	45	50	60	60	70
EM Level in Opp. Ear	60	60	80	75	75	75	85	110	105									

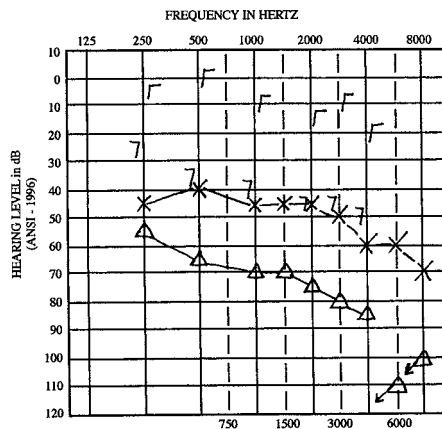
BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT						FOREHEAD						LEFT					
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type WB ☐ NB ☒	25*	35*	40*	45*	45*	50*	5	0	10	15	10	20	5*	0*	10*	15*	10*	20*
EM Level in Opp. Ear	75	85	85	85	95	100							55	65	70	75	80	85

Pure Tone Average		2 Freq	3 Freq	Variable	WEBER						Pure Tone Average	2 Freq	3 Freq	Variable
68		70	77		L	L	L	L	L	L	43	43	50	

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☐	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
	List	HL	%	%	List	HL	%	%
EM Level in Opp. Ear								



Speech Presentation

MLV Recorded
SRT ☐ ☐
WRS ☐ ☐
COMMENTS

AUDIOGRAM KEY	
Right	Left
AC Unmasked	AC Unmasked
AC Masked	AC Masked
BC Masked Unmasked	BC Masked Unmasked
BC Masked Masked	BC Masked Masked
BC Forehead Masked	BC Forehead Masked
Both	
BC Forehead Unmasked	BC Forehead Unmasked
Sound Field (unaided)	Sound Field (unaided)
Sound Field (aided)	Sound Field (aided)
Opp Ear Masked	Opp Ear Masked
Examples of No Response Symbols	
[Symbol]	[Symbol]

FIGURE 6.8 Audiogram showing a mixed hearing loss in the right ear and a conductive hearing loss in the left ear. Unmasked results showed conductive hearing losses in both ears. Masking was indicated for the right ear for air conduction, showing only slight threshold shifts. Masking for bone conduction was indicated for both ears, resulting in threshold shifts for the right ear. The Weber test refers consistently to the left ear, which has the better sensory/neural sensitivity. Note that no response is obtained in the right ear by air conduction at 6000 and 8000 Hz with masking in the left ear.

Masking for SRT

Masking must sometimes be used in SRT testing to eliminate the influence of the nontest ear and to ascertain the true threshold of the test ear when cross hearing is a possibility. As in pure-tone testing, the audiologist should suspect the need to mask more often than cross hearing actually occurs. Even in questionable cases masking is a prudent practice.

5. A significant reason for using insert receivers during speech audiometry is that they

The use of insert earphones can help to avoid some of the problems of overmasking for speech as it does for pure tones by increasing interaural attenuation to at least 70 dB. The recent emphasis on their use holds promise for solving many masking dilemmas encountered when using supra-aural earphones.

Cross Hearing in SRT Tests

Problems involving cross hearing exist for SRT measurements for the same reasons that they do for pure-tone air-conduction tests. In some cases the notion persists that there must be a significant difference between the SRTs of the two ears before suspicions of cross hearing arise (Martin et al., 1998). This action ignores the current knowledge that sounds contralateralize by bone conduction rather than by air conduction. Cross hearing is a danger whenever the SRT of the test ear, minus the interaural attenuation (conservatively set at 40 dB for supra-aural earphones and 70 dB for insert earphones), is greater than or equal to the bone-conduction thresholds of the nontest ear. Because speech is a complex signal and bone-conduction thresholds are obtained with pure tones, it must be decided which frequency to use in computation. Martin and Blythe (1977) found that frequencies surrounding 250 Hz do not contribute to the recognition of spondee presented to the opposite ear until levels were reached that considerably exceeded normal interaural attenuation values. Their research supports the recommendations later made by ASHA (1988) that the SRT of the test ear should be compared to the lowest (best) bone-conduction threshold of the nontest ear at 500, 1000, 2000, or 4000 Hz.

The following formula will reveal when cross hearing may occur and masking of the nontest ear must be used in the test

$$\text{SRT}_{\text{TE}} - \text{IA} \geq \text{best BC}_{\text{NTE}}$$

Noises Used in Masking for Speech

The types of masking noises used for speech audiometry are more limited than those used for pure tones. Because speech is a broad-spectrum signal, speech-masking noises must consist of a broad band of frequencies. White noise is available on many diagnostic audiometers. Because it is a broad-spectrum noise, it masks speech satisfactorily, but is slightly less intense in the low frequencies.

Speech noise is obtained by filtering white noise above 1000 Hz at the rate of about 12 dB per octave. Speech noise provides more energy in the low-frequency spectrum than does white noise and is more like the overall spectrum of speech. Of the masking noises available on commercial audiometers, speech noise is usually preferred for masking speech.

Calibration of Speech-Masking Noises

All of the needs for adequate control of the masking system for pure tones are identical to those for speech. The linearity of the masking-level dial must be proved. If the masking circuit is calibrated in decibels of effective masking, procedures for masking speech can be carried out in the

same way as those used for pure tones. Psychoacoustic calibration for effective masking may be carried out in the following fashion on a group of normal-hearing subjects:

1. Present a series of spondees at 30 dB HL.
2. Present a noise (preferably speech noise) to the same earphone.
3. Raise the level of the noise in 5 dB steps until subjects miss more than 50% of the words. Recheck this several times.
4. Obtain a mean for the dial reading on the noise attenuator that masked speech at 30 dB HL. This is 30 dB EM for speech.
5. Subtract 30 dB from what was determined in step 4.
6. Add a safety factor of 10 dB to ensure masking effectiveness for most cases.
7. Post a correction chart showing the amount of noise that must be added to 0 dB HL (shown in step 6). This is 0 dB EM for speech.

Once calibration is completed, speech at any level can be masked when an effective masking level equal to the SRT plus the predetermined correction factor is introduced into the same ear. In other words, to mask an SRT of 45 dB HL, the hearing level of the masker must be set at 45 dB plus the correction factor to reach a level of 45 dB EM.

6. Calibration of effective masking for speech is typically carried out _____.

Central Masking for Speech

It has been demonstrated that threshold shifts for continuous discourse (Martin, Bailey, & Pappas, 1965) and for spondaic words (Martin, 1966) occur when a noise is presented to the nontest ear under earphones. Because the levels of noise need not be high enough to cause peripheral masking by cross-conduction, it is assumed that the same central masking phenomenon exists for speech as for pure tones. Martin and DiGiovanni (1979) found smaller threshold shifts due to central masking than had been previously reported, but it should be expected that a threshold shift of about 5 dB will be seen for speech in the presence of a contralateral noise, even if that noise is of relatively low intensity (Konkle & Berry, 1983).

Masking Methods for SRT

Figure 6.9 illustrates the possibility of cross hearing for SRT. Assuming the use of supra-aural earphones the difference between the SRT of the test ear (45 dB) and the minimal interaural attenuation (40 dB) exceeds the bone-conduction threshold (0 dB) of the nontest ear. In this example, no specific frequency is referred to in terms of the bone-conduction threshold. In actual clinical practice, the SRT of the test ear is compared to the best (lowest) bone-conduction threshold of the nontest ear at 500, 1000, 2000, or 4000 Hz. If the nontest ear originally participated in the test, it should be removed by presenting an *initial* level of effective masking equal to the SRT of the masked ear plus the correction factor. If the SRT of the test ear does not shift by more than 5 dB (for central masking), the original threshold was correct as measured, and masking is completed. This is true because the nontest ear was rendered incapable of test participation. If the threshold shifted by more than 5 dB, the implication is that the nontest ear did, in fact, play a role in unmasked results by cross hearing. When original speech stimuli have been cross heard, further testing using the plateau method is required.

Maximum masking for speech follows the same general rules noted previously for pure tones. If cross hearing has taken place, the patient's interaural attenuation is no greater than the

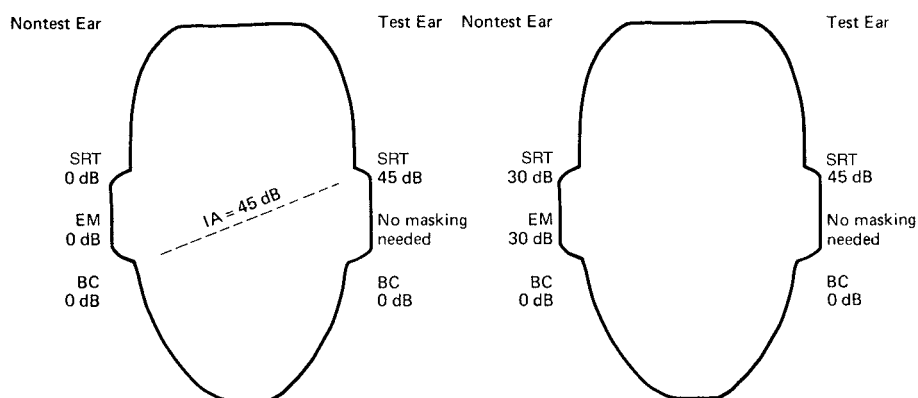


FIGURE 6.9 Possible cross hearing during SRT testing. Both A and B show that the difference between the SRT of the test ear and the lowest bone-conduction threshold of the nontest ear exceed the minimum interaural attenuation found when speech sounds contralateralize (40 dB). Note that the SRT of the nontest ear in A is 0 dB HL and in B it is 30 dB HL. The SRTs of the nontest ears are unrelated to the danger of cross hearing for speech. The SRT of the test ear must be compared to the lowest bone-conduction threshold of the nontest ear. The initial effective masking level for the SRT is equal to the SRT of the nontest ear (i.e., 0 dB EM for A, 30 dB EM for B).

SRT of the test ear, minus the lowest bone-conduction threshold of the nontest ear. When a level of effective masking, minus the *patient's* interaural attenuation, is equal to or above the lowest bone-conduction threshold of the test ear, overmasking (OM) has occurred.

$$OM = EM_{NTE} - IA \geq \text{Best } BC_{TE}$$

The Plateau Method

The plateau method as described for pure tones can be used when measuring the SRT. If testing with the initial level of effective masking reveals that the SRT was obtained by cross hearing, the SRT is determined with that level of noise in the nontest ear. Then, the intensity of the noise is raised 5 dB in the nontest ear, and spondaic words are again presented to the test ear. If fewer than three out of six words can be repeated correctly, the level of the words is raised 5 dB, and so forth. The true SRT is reached when the intensity of the noise can be raised or lowered at least three times in 5 dB steps without affecting the threshold for the words. As in the case of pure tones, the plateau for speech is influenced by the patient's interaural attenuation, the bone-conduction thresholds of the test ear, and the SRT of the masked ear.

Recording Masked SRT Results

Before SRTs are recorded on the audiometric worksheet, a 5 dB correction for central masking should be subtracted from the SRT obtained with contralateral masking, assuming the initially measured SRT had shifted. The maximum level of effective masking required to obtain threshold must be recorded in the appropriate box below the SRT.

Cross Hearing and Masking in Speech-Recognition Tests

Given that speech-recognition tests are delivered at suprathreshold levels, the danger of cross hearing is even greater than during threshold tests. Because cross hearing of an air-conducted signal occurs by bone conduction, the likelihood of opposite-ear participation in a speech-recognition test increases as the level of the test signal increases. In addition, the better the bone-conduction threshold in the nontest ear, the greater is the probability that it will be stimulated by speech delivered to the test ear. In other words, whenever the hearing level of the stimuli minus the interaural attenuation equals or exceeds the lowest bone-conduction threshold of the nontest ear, cross hearing is a strong probability. Expressed as a formula,

$$\text{SRSHL}_{\text{TE}} - \text{IA} \geq \text{best BC}_{\text{NTE}}$$

As in the case of the SRT, the interaural attenuation is considered to be as little as 40 dB for supra-aural earphones and 70 dB for insert earphones, and the bone-conduction threshold inserted in the formula is the lowest (i.e., the best) one obtained in the nontest ear at 500, 1000, 2000, or 4000 Hz.

Whenever masking is needed during SRT testing, it will always be needed for speech-recognition testing for the same ear. Often, however, masking becomes necessary only when the level of speech is raised above the SRT for the speech-recognition test. Whatever masking noise is available for SRT should be used as well for finding the SRS. The noise should be calibrated as effective masking for speech, as discussed earlier. Although several masking methods have been suggested, the one described here has been found to be most useful (Martin, 1972). The effective masking level for the masked ear is equal to the hearing level at which the speech-recognition test is performed (HL), plus the correction factor (CF), minus 40 dB for interaural attenuation (70 dB if insert receivers are used) plus the largest air-bone gap in the masked ear:

$$\text{EM} = \text{HL}_{\text{TE}} + \text{CF} - \text{IA} + \text{ABG}_{\text{NTE}}$$

The effective masking level thus derived is just sufficient to mask speech at the nontest ear if the interaural attenuation is as low as 40 dB (or 70 dB if insert receivers are used), and it is more than enough noise if the IA is greater than these amounts (a probability). If the interaural attenuation can be computed on the basis of masking needs for SRT, the larger number should be used in the formula, which lowers the effective masking level and decreases the chance of overmasking. The interaural attenuation can never be less than the unmasked SRT of the test ear minus the lowest bone-conduction threshold of the nontest ear.

Insert receivers for speech-recognition testing have several distinct advantages over supra-aural audiometer earphones, and the two types of receivers may be used interchangeably for measuring SRS assuming proper equipment calibration (Martin, Severance, & Thibodeau, 1991). Presenting speech through an insert receiver increases the interaural attenuation from the test ear to the nontest ear. For example, substituting 70 dB for 40 dB as the minimum amount of interaural attenuation in the formula shown previously for determining the need to mask during speech-recognition testing will eliminate masking entirely for a large number of patients. When masking is required, if it is delivered through an insert receiver, the possibility of overmasking is reduced or eliminated because the interaural attenuation of the masking noise from nontest ear to test ear will likewise be increased. Finally, the attenuation of

7. Because tests of SRS are suprathreshold, they require masking _____ (more/less) often than speech threshold tests.

background noise that is provided by insert phones relative to supra-aural phones may result in improved speech recognition when testing is done at low sensation levels or when background noise is a problem.

Whenever the nontest ear is masked for speech-recognition tests, just as for other audiometric measures, the level of effective masking should be indicated on the audiometric worksheet. In this way, if someone other than the examiner should review the test results, the precise effective masking level that was used in testing can be seen.

Clinical Commentary

As with pure-tone masking, the use of insert receivers can often completely eliminate the need for masking during speech audiometry, thereby simplifying testing. When masking is needed, problems of overmasking are far less common than when supra-aural earphones are used.

Compensation for Central Masking

If the SRT was obtained with contralateral masking, the central masking correction of 5 dB may have been subtracted before the result was recorded. This correction must be borne in mind when setting the hearing level for the speech-recognition test. If masking is required for finding the SRS, but not for determining the SRT, the clinician should assume that a 5 dB shift would have occurred if masking had been used when finding the SRT. In such cases, the hearing level should be increased for speech-recognition testing to compensate for the loss of loudness of the speech signal that results when noise is presented to the nontest ear.

Maximum Masking

Just as the need for masking increases as the hearing level is increased for the test stimuli, so does the necessary masking level increase. The possibility of overmasking increases as the level of noise is raised in the masked ear. Rules for maximum masking and overmasking for speech are given in the section on speech-recognition threshold and should be scrutinized carefully when masking for suprathreshold speech-recognition tests.

Summary

When cross hearing occurs, proper masking procedures must be instituted to overcome this problem. The approach for pure-tone air- and bone-conduction tests is very similar to that for the SRT. They involve using an initial effective masking level equal to the unmasked threshold of the nontest ear plus a predetermined correction factor. Since SRS tests are done at suprathreshold levels, it is not necessary to first determine unmasked results. In fact, that can be very misleading. The method used when masking for SRS involves more in the ways of formulas and computations but are very practical for the clinical audiologist. These propositions are illustrated in Figure 5.5 (page 124) where masking was needed for the SRS test delivered at 90 dB HL and Figure 5.6 (page 125) where masking was required for a number of tests.

REVIEW TABLE 6.1 Masking for Pure-tone Hearing Tests

Minimal interaural attenuation is considered to be 40 dB for supra-aural earphones and 70 dB for insert earphones

<i>Test</i>	<i>Air Conduction (AC)</i>	<i>Bone Conduction (BC)</i>
When to mask	When difference between AC (test ear) and BC (nontest ear) exceeds minimal IA	When there is an air-bone gap greater than 10 dB in the test ear
How to mask	Initial masking: IM = AC of nontest ear. If tone not heard, plateau	Same as AC plus occlusion effect in masked ear
Overmasking occurs	When EM level in masked ear minus IA is equal to or greater than BC of test ear at same frequency	Same as AC

REVIEW TABLE 6.2 Masking for Speech Hearing Tests

Minimal interaural attenuation is considered to be 40 dB for supra-aural earphones and 70 dB for insert earphones

<i>Test</i>	<i>Purpose</i>	<i>Material</i>	<i>Unit</i>	<i>When to Mask</i>	<i>Initial Masking</i>
SRT	HL for speech recognition Verify PTA	Spondees; Cold running speech	dB	$SRT_{TE} - 40 \geq BBC_{NTE}$	EM = SRT_{TE} If over 5 dB, shift plateau
SDT	HL for speech awareness	Cold running speech	dB	$SDT_{TE} - 40 \geq BBC_{NTE}$	EM = SDT_{TE}
MCL	Comfort level for speech	Cold running speech	dB	$SDT_{TE} - 40 \geq BBC_{NTE}$	EM = $BBC_{TE} + 40$ dB
UCL	Level at which speech becomes uncomfortably loud	Cold running speech	dB	$UCL_{TE} - 40 \geq BBC_{NTE}$	EM = $BBC_{TE} + 40$ dB
RCL (DR)	Dynamic listening range for speech	Cold-running speech	dB		
WRS	Recognition of speech	PB words; CNC words; rhyming words; sentences	%	$HL_{TE} - 40 \geq BBC_{NTE}$	$HL_{TE} - IA + ABG_{NTE}$

TE = test ear; NTE = nontest ear; PTA = pure-tone average; EM = effective masking; IA = interaural attenuation; BBC = best (lowest) bone-conduction threshold.

Study Questions

1. When is masking needed for pure-tone air- and bone-conduction tests, for SRT and SRS testing?
2. What role does the occlusion effect play in masking for bone conduction?
3. How is calibration for effective masking carried out?
4. What is the masking plateau?
5. How do insert receivers help to avoid problems in overmasking?

Suggested Readings

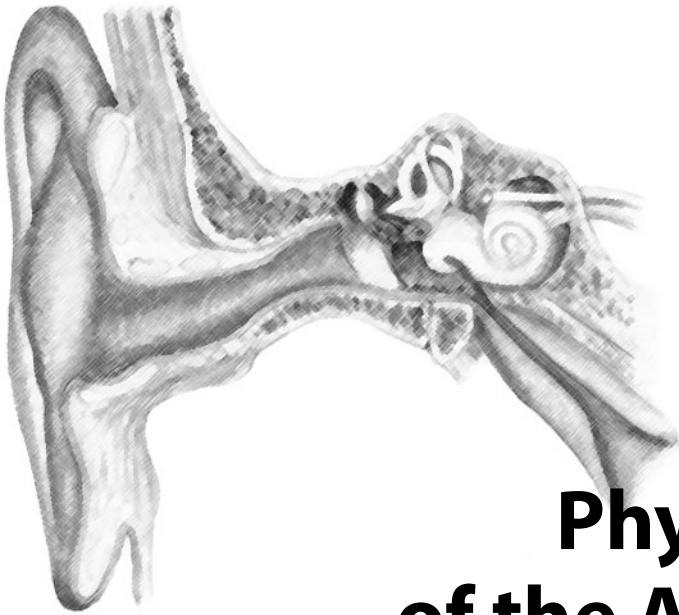
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Endnote

1. For Karl F. Gauss, German mathematician and physicist, 1777–1855

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Physiological Tests of the Auditory System

AT THIS POINT THE READER should have a good grasp of the tests described earlier, as well as a general knowledge of how the ear is constructed and how it responds to sound. The comprehensive audiometric evaluation is defined by most insurance companies as administration of air- and bone-conduction pure-tone audiometry and speech audiometric measures comprising speech-recognition threshold and speech-recognition score. While some of the tests described in this chapter have become routine within audiology clinics, others are reserved for more special occasions when additional diagnostic information is required. An understanding of the procedures to follow is essential to the study of clinical audiology. It will allow readers to more fully comprehend the examples of different hearing disorders caused by damage to different parts of the auditory system, which will be described in Chapters 9 through 12.

Diagnostic procedures beyond basic audiometrics can be separated into the categories of tests of function and tests of structure. Audiologists are concerned with the former, inferring specific lesions based on a constellation of test results. Modern medicine, with the development of imaging techniques, looks directly at the structure of, for example, specific areas within the auditory system. The development of these remarkable imaging procedures does not mitigate the importance of audiological procedures, but rather the two exist in a synergistic fashion.

The procedures described in this chapter require the use of specially designed equipment. With this equipment, audiologists can now accumulate valuable information for diagnostic purposes from a variety of procedures. These tests measure impedance and compliance in the plane of the tympanic membrane, tiny echoes whose presence can estimate the integrity of the inner ear and changes in the pattern of electrical activity in the inner ear and brain in response to acoustic stimuli. As a historical footnote, a brief review of earlier, behavioral site-of-lesion measures will be presented.

LEARNING OBJECTIVES

The purpose of this chapter is to discuss some of the electroacoustical and electrophysiological procedures that have been developed that serve both as indices of hearing sensitivity and as indications of the site of a lesion in the auditory system. These tests do not require behavioral responses from patients. Upon completion of this chapter, the reader should be able to

- Discuss the purpose of acoustic immittance testing and, following supervised practice, perform tympanometry and acoustic reflex testing on a fellow student or friend.
- Describe the expected immittance results for several different ear pathologies.
- Define the differences among spontaneous, transient-evoked, and distortion-product otoacoustic emissions.
- Describe how evoked auditory potentials are measured and what these measures can reveal about hearing function and the site of lesion within the auditory system.

 Acoustic Immittance

Measurements of acoustic **immittance** have become as routine in the audiological test battery as pure-tone and speech audiometry. Immittance measures guide the diagnostic audiologist in identifying abnormalities in the auditory system in a number of ways. The introduction of acoustic immittance measures more than three decades ago was a milestone in audiology, and most audiologists would agree that this procedure is basic to the test battery.

For a number of years, interest was directed toward the effects of various kinds of pathology on **acoustic impedance** in the plane of the tympanic membrane. Initially, most impedance measurements were made with mechanical devices too clumsy and too difficult to use routinely. A variety of commercial electroacoustic impedance meters (e.g., Figure 7.1) are commonly used by audiologists today. Most devices measure **compliance**, which is related to the dimensions of an enclosed volume of air as expressed on a scale of different units of measurement. Examples of the different units are cubic centimeters (cm^3) or milliliters (ml) of an equivalent volume of air in the middle ear.

Several terms have been used to describe the various measurements made in the plane of the tympanic membrane. The word *immittance* is used as an all-encompassing term to describe measurements made of tympanic membrane impedance, compliance, or admittance. The American National Standards Institute (ANSI, 2007) has adopted a set of standards that define both the characteristics of instruments used in the measurement of acoustic immittance and the associated terminology.

Acoustic immittance measures have been called “impedance audiometry.” Because audiometry *per se* is involved only with respect to the acoustic reflex, this term is not strictly accurate. Determinations of acoustic immittance are also frequently called “middle-ear measurements,” which is also misleading since the measurements are not actually made of the middle ear. All determinations of middle-ear function are indirectly made by measurements made in the plane of the tympanic membrane.



FIGURE 7.1 An electroacoustic immittance meter for the assessment of middle-ear function can measure the mobility of the tympanic membrane, the air pressure within the middle-ear cavity, and the presence of the acoustic reflex. Bluetooth wireless technology allows transmission of collected data to be sent to an off-ice computer for storage and printing. (Courtesy of GN Otometrics)

Measurements Made on Acoustic Immittance Meters

Basically, three measurements are made in the plane of the tympanic membrane:

1. **Static acoustic compliance** (static acoustic admittance), which is the mobility of the tympanic membrane in response to a given value of air pressure in the external ear canal.
2. **Tympanometry**, which is a measurement of middle-ear pressure, determined by the mobility of the membrane as a function of various amounts of positive and negative air pressure in the external ear canal (the more positive or negative the air pressure in the external ear canal, the more the normal middle-ear system becomes immobilized, or “clamped”).
3. Contraction of the middle-ear muscles, known as the **acoustic reflex**, in response to intense sounds, which has the effect of stiffening the middle-ear system and decreasing its static acoustic compliance.

1. The three basic acoustic immittance tests are _____, _____, and _____.

These basic tests and their expected results on various pathologies are discussed in the appropriate portions of Chapters 10 to 12.

Factors Governing Acoustic Immittance

The reader will recall from Chapter 3 that the impedance (Z) of any object is determined by its frictional resistance (R), mass (M), and stiffness (S). The effects of mass and stiffness are critically dependent on the frequency (f) of the sound being measured. The formula for impedance is stated as

$$Z = \sqrt{R^2 + \left(2\pi fM - \frac{S}{2\pi f}\right)^2}$$

The combination of mass and stiffness (contained within the parentheses in the formula) is called complex resistance or **reactance**. Simple resistance is obviously independent of the rest of the formula, whereas mass reactance and stiffness reactance are inversely related to each other and are critically dependent on frequency. As frequency increases, the total value of the mass reactance factor also increases. Conversely, as frequency goes up, the effects of stiffness reactance diminish. Mass is therefore the important factor in the high frequencies, and stiffness is the important factor in the low frequencies. As the stiffness of a system increases, it is said to become less compliant; that is, it becomes more difficult to initiate motion. Compliance, therefore, is the inverse of the stiffness factor of the formula.

The anatomy of the ear was described in a cursory fashion in Chapter 2. Details are brought out in Chapters 9 through 12, and the effects of various disorders on immittance are discussed. For the present, however, the following general assignments of values can be made: Resistance is determined primarily by the ligaments that support the three bones in the middle-ear cavity. The mass factor is determined primarily by the weight of these three tiny bones and the tympanic membrane. Stiffness is primarily determined by the load of fluid pressure from the inner ear on the base of the stapes, the most medial bone of the middle ear. The ear, therefore, is largely a stiffness-dominated system, at least in response to low-frequency sounds.

Clinical Commentary

In pure-tone air- and bone-conduction testing, one finds that many conductive hearing losses have their greatest, or earliest, decrease in hearing for the lower frequencies. As most conductive hearing losses tend to stiffen the middle-ear system, this finding would be expected from the above impedance formula as the effect of stiffness is lessened as frequency increases. There are, however, many exceptions to this, so it can be a dire mistake to diagnose a conductive loss, or any other kind of loss, based on the curve of the air-conduction audiogram.

Equipment for Middle-Ear Immittance Measurements

An electroacoustic immittance meter is diagrammed in Figure 7.2. Three small plastic or rubber tubes are attached to a metal probe, which is fitted into the external ear canal with an airtight seal. A plastic or rubber cuff, placed around the probe, can be varied in size to accommodate most ears. The three tubes are connected to (1) a miniature loudspeaker, which emits a pure tone, usually at 220 or 226 Hz (the incident wave), although a growing number of instruments have the capability of testing at higher-frequency probe tones as well; (2) a tiny microphone, which picks up the sound in the external ear canal (the sound comprising both the incident wave introduced to the ear from the speaker and the reflected wave as it returns from the tympanic membrane); and (3) an air pump, which can create either positive or negative air pressure within the canal. The air pump is calibrated in milliliters (ml), millimeters of water (mm H₂O), or dekapascals (daPa) (10 Pascals). The units of measurement are very similar—1 daPa = 1.02 mm H₂O, and 1 mm H₂O = 0.98 daPa—when measurements are made at standardized conditions of temperature and pressure. The devices must be calibrated so that

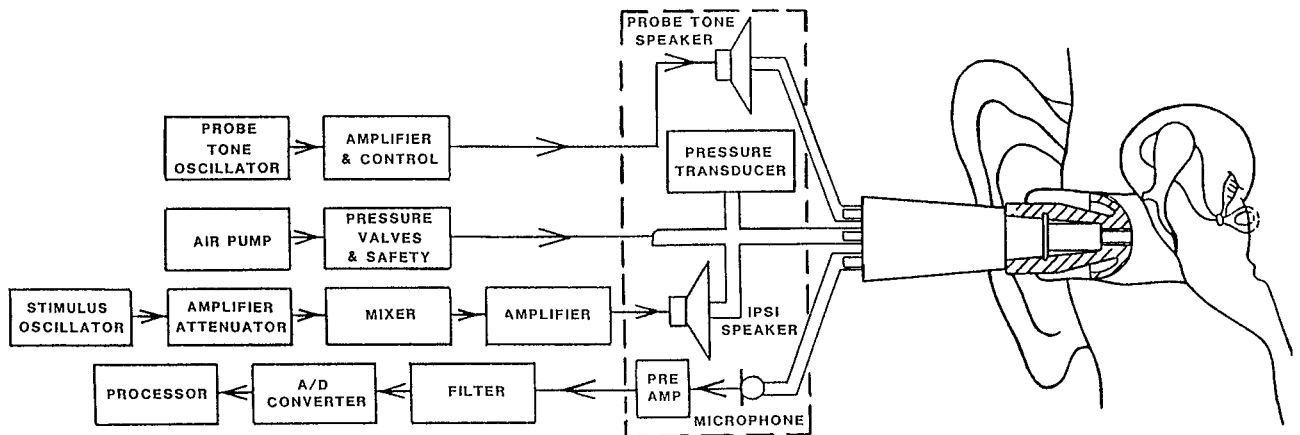


FIGURE 7.2 Diagram of an electroacoustic immittance meter showing its three primary components: a speaker to present a tone to the ear, a microphone to measure the intensity of the tone as it is reflected from the tympanic membrane, and an air-pressure pump to vary the pressure within the external auditory canal. (Courtesy of Grason-Stadler Co.)

0 daPa (or 0 mm H₂O, or 0 ml) is equal to atmospheric pressure at the site where measurements are to be made. The probe is attached to one side of a headset. An earphone connected to an acoustic reflex activator system is attached to the opposite side (Figure 7.3) and functions as a built-in pure-tone audiometer.

Measurement of Static Acoustic Compliance

For static acoustic compliance to be measured, the ear canal should first be cleared of any occluding earwax or other debris. Even the smallest amount of material in the ear canal may clog one of the tiny probe tubes and make measurements impossible or very misleading. The ear tip is pressed into the ear canal, a tight seal is obtained, and positive pressure is increased with the air pump. Observation of the meter will indicate whether the necessary airtight seal has been obtained, or whether resealing, perhaps with a different-sized tip, is necessary. Once the seal is obtained, the pressure is increased to +200 daPa. On most instruments the intensity of the probe tone is automatically adjusted until the desired sound-pressure level is obtained, usually 85 to 90 dB. The clinician can then determine the **equivalent volume** in cubic centimeters. Today's immittance meters make an automatic notation of this important first reading. This measurement, made with the tympanic membrane loaded with +200 daPa of pressure, is called c_1 . This first measurement, c_1 , therefore, is made with the tympanic membrane immobilized by positive air pressure, and it primarily represents the compliance of the outer ear.

Clinical Commentary

The concept of "equivalent volume in cubic centimeters" for the c_1 reading gives a high clinical relevance to this first measure. The average volume of air in the human ear canal varies from approximately 0.5 cc in young children to 1.5 cc in adults. An important clinical observation in compliance measures rests in the fact that very high c_1 readings are indicative of even the smallest of perforations in the tympanic membrane. It should be noted, however, that a normal volume reading can be obtained in an ear with a tympanic membrane perforation in the presence of active middle-ear disease.



FIGURE 7.3 Arrangements for acoustic immittance testing. (A) A subject configured with the probe assembly in the right ear and an insert earphone in the left ear. The shoulder harness kit is placed on the right shoulder. With this arrangement tympanometry, static compliance, and ipsilateral acoustic reflexes can be tested in the right ear and contralateral acoustic reflexes can be tested in the left ear. (B) The same subject configured with the probe assembly in the left ear and an insert earphone in the right ear. The shoulder harness kit is placed on the left shoulder. With this arrangement tympanometry, static compliance, and ipsilateral acoustic reflexes can be tested in the left ear and contralateral acoustic reflexes can be tested in the right ear.

2. One dekapascal is
equal to _____ Pascals.

The second step in determining static acoustic compliance is attained when the pressure in the external ear canal is gradually decreased until the tympanic membrane achieves maximum compliance—that is, when pressures on both sides of the membrane are approximately equal. Another reading is taken, called c_2 , which represents static acoustic compliance of the outer ear and middle ear combined. Many audiologists believe that c_2 should be measured with outer-ear pressure at 0 daPa (the ambient air pressure). The static acoustic compliance of the middle ear (c_x) can then be determined by working through this formula:

$$c_x = c_2 - c_1$$

During conditions for measurement of c_1 , the tympanic membrane's relative immobility causes a good deal of energy to be returned to the probe, raising the sound-pressure level in the external ear canal. The membrane's increased mobility during the c_2 measurement allows more energy to be admitted to the middle ear, lowering the sound pressure between the tympanic membrane and the probe. The static acoustic compliance of the middle ear (ME) mechanism is the difference between these two conditions, which cancels out the compliance of the external auditory canal (EAC). Stated as a formula,

$$c_x (\text{ME}) = c_2 (\text{EAC} + \text{ME}) - c_1 (\text{EAC})$$

TABLE 7.1 Normative Ranges for Static Admittance (Compliance), Tympanometric Width (TW), and Equivalent Ear Canal Volume (V_{ea}). (Data from Margolis & Hunter, 2000)

Age	Admittance/Compliance	TW(daPa)	V_{ea} (cm^2)
Children (3 to 10 years)	0.25 to 1.05	80 to 159	0.3 to 0.9
Adults (> 18 years)	0.30 to 1.70	51 to 114	0.9 to 2.0

Normal Values for Static Acoustic Compliance. Research over the years has not led to agreement on what values constitute normal static acoustic compliance. Studies have concluded that there are differences between adults and children and among the various probe-tone frequencies available. Most devices disregard the phase angle of the incident (original) and reflected waves in the ear canal. The fact that there is considerable variability for normal ears, often overlapping middle-ear conditions that cause high or low compliance, significantly reduces the value of this portion of immittance testing. Normative values of static compliance for children and adults are given in Table 7.1. The normal range is broad, and a patient's middle-ear compliance values really cannot be considered abnormal unless one of the extremes is clearly exceeded. Even in individuals with normal middle ears, the values of static compliance vary with both age and gender.

Recording and Interpreting Static Acoustic Compliance. Most modern clinics use devices that make these measurements automatically and provide a paper printout with the compliance values for each ear tested. Compliance values below the normal range suggest some change in the stiffness, mass, or resistance of the middle ear, causing less than normal mobility of the tympanic membrane. This may result from fluid accumulation in the normally air-filled middle ear or immobility of the chain of middle-ear bones. Reduced elasticity of the tympanic membrane may be due to age or caused by partial healing of a previous perforation. High compliance suggests some interruption in the chain of bones, possibly caused by disease or fracture, or by abnormal elasticity of the tympanic membrane. If static compliance values are determined manually, the data can be recorded on an immittance form (Figure 7.4f).

Although static acoustic compliance measures are an integral part of any audiological workup, like any diagnostic test, they can be misleading. It is possible for different abnormalities of the ear to have opposing effects, resulting in what appear to be essentially normal immittance values (Popelka, 1983).

3. Abnormally high static compliance suggests _____.

Tympanometry

The tympanic membrane vibrates most efficiently when the pressure on both sides is equal. This statement is basic to the understanding of tympanometry. As the membrane is displaced from its resting position by positive or negative pressure in the external ear canal, the vibratory efficiency of the membrane is decreased. Tympanometry is performed by loading the tympanic membrane with air pressure equal to +200 daPa, measuring its compliance, and then making successive measurements of compliance as the pressure in the canal is decreased. After the pressure has reached 0 daPa (atmospheric pressure), negative pressure is created by the pump, and additional compliance measurements are made. The purpose of tympanometry is to determine the point and magnitude of greatest compliance of the tympanic membrane. Such measurements give invaluable information regarding the condition of the middle-ear structures. Performing tympanometry immediately after

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IMMITTANCE										
NAME: Last - First - Middle				SEX	AGE	DATE	EXAMINER		INSTRUMENT	
ACOUSTIC REFLEXES										
		RIGHT				LEFT				
	Frequency (Hz)	500	1000	2000	4000	500	1000	2000	4000	
a	Ipsilateral (Probe same)									
b	Contralateral (Probe opposite)									
c	Audiometric Threshold									
d	Reflex SL									
e	Decay Time (Seconds)									
STATIC COMPLIANCE										
	Tymp. Width	M.E. Pressure	C ₁ Volume	C ₂	C ₁ Compliance	Tymp. Width	M.E. Pressure	C ₁ Volume	C ₂	C ₂ = C ₁ - C ₁
f										
TYMPANOGRAMS										
g	RIGHT				LEFT					

FIGURE 7.4 Form for recording results of immittance measures: (a) acoustic reflexes obtained with the probe-tone and reflex-eliciting stimulus presented to the same ear; (b) contralateral acoustic reflex thresholds; (c) behavioral thresholds obtained during standard pure-tone audiometry; (d) sensation levels of the reflexes (b minus c); (e) the number of seconds required for the reflex to decay to half of its original amplitude; (f) static compliance; (g) graphs (the tympanograms) showing the pressure-compliance functions for both ears can be pasted here.

determining c_1 allows determination of both c_2 and the ear-canal pressure required for measuring acoustic reflex thresholds.

Tympanometry is generally conducted with a low-frequency probe tone of 220 or 226 Hz. The use of higher-frequency probe tones, or a succession of different frequencies, can modify results in a variety of ways, making this test more valuable diagnostically (Shanks, Lilly, Margolis, Wiley, & Wilson, 1988). The difficulties encountered in the use of multifrequency tympanometry are mitigated by the newest generation of devices, which are microprocessor controlled.

Recording and Interpreting Tympanometric Results. Compliance measurements are usually recorded directly and automatically on a graph called a **tympanogram**, which shows compliance on the y-axis and pressure, in dekapascals, on the x-axis. The results of this automatic printout may be appended to the form designed to record immittance measures (Figure 7.4g).

Jerger (1970) has categorized typical tympanometric results into different types. This classical description of tympanometric shape is widely used despite the fact that shape classification is a qualitative assessment that lends a degree of clinical subjectivity to the measures. To facilitate direct comparison, all five classical tympanogram types are illustrated on the same form (Figure 7.5).

Type A. Type A curves are seen in patients who have normal middle-ear function. The point of greatest compliance is at 0 daPa, and the curve is characterized by a rather large inverted V.

Type A_s. Type A_s curves show the same characteristic peak at or near 0 daPa, suggesting normal middle-ear pressure; however, the peak is much shallower than that of the usual Type A. Type A_s

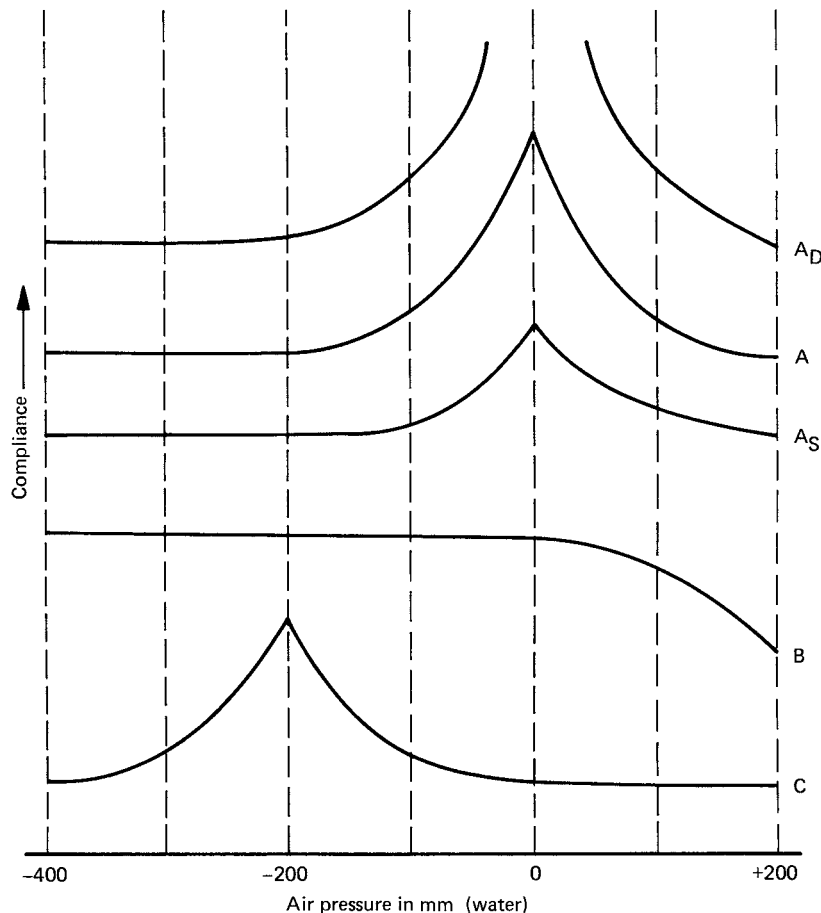


FIGURE 7.5 Five typical tympanograms, labeled by their classical descriptions, illustrating various conditions of the middle ear. Type A shows normal pressure-compliance functions and is typical of normal middle ears. Type A_S curves are like the A curves but are much shallower and are associated with stiffness of the stapes, the smallest of the middle-ear bones. Type A_D curves are much deeper than the normal Type A curves, and are symptomatic of interruptions in the chain of middle-ear bones or flaccidity of the tympanic membrane. Type B shows no pressure setting at which the tympanic membrane becomes most compliant, and suggests fluid in the middle-ear space. Type C shows the tympanic membrane to be most compliant when the pressure in the ear canal is negative, suggesting that the pressure within the middle-ear space is below atmospheric pressure.

curves are often seen in patients in whom the stapes has become partially immobilized. The “S” may stand for “stiffness” or for “shallow.”

Type A_D. In some cases the general Type A pattern is preserved; however, the amplitude of the curve is unusually high, or in some cases the positive and negative sides of the spike do not meet at all in Type A_D curves. Such curves may be associated with flaccidity of the tympanic membrane or separation of the chain of middle-ear bones. The “D,” therefore, may stand for “discontinuous” or for “deep.”

Type B. Type B curves are seen when the middle-ear space is filled with fluid. Because even wide variations of pressure in the external ear canal can never match the pressure of fluid

4. Type C tympanograms suggest

behind the tympanic membrane, the point of greatest compliance cannot be found. Type B curves may also be seen when a small amount of earwax or other debris occludes one of the tiny tubes within the probe, when a wax plug blocks the external ear canal, or when there is a hole in the tympanic membrane so that the meter measures the compliance of the rigid walls of the middle ear. Therefore, when Type B curves are evident, the clinician should make certain that these factors are not present.

Type C. In certain conditions, discussed in Chapter 10, the pressure in the middle ear falls below normal. In such cases the tympanic membrane becomes most compliant when the pressure in the ear canal is negative, thus equaling the middle-ear pressure. When maximum tympanic membrane compliance occurs at a negative pressure of 200 daPa or greater, middle-ear pressure is considered to be abnormally negative.

At times it may erroneously appear that a tympanogram is flat, missing a peak pressure point. This can be due to negative middle-ear pressure that is so extreme that the peak pressure point does not appear. In cases of “flat” tympanograms, it is often advisable to make immittance measures as low as 400 daPa. Such extremely negative middle-ear pressure may have significant medical effects on the patient, and they should be pointed out to the physician managing the case, or a medical referral should be made.

On occasion, a peak pressure point is observed in patients at positive pressures greater than +50 daPa. This is sometimes seen in children who have been crying, patients who have blown their noses, and so on. It is likely that any such condition is short-lived, and normal middle-ear pressure will become restored in a short time. If positive peak pressure is observed for longer than a brief period, it might be advisable to ask for a medical consultation.

5. The tympanograms of people with normal hearing may be identical to those of patients with _____ hearing loss.

A number of factors may influence the outcome of tympanometry. When pressure is varied from positive to negative, the peak of the wave is lower than when pressure is changed from negative to positive, although this rarely affects the interpretation of results. Performing tympanometry with different probe tone frequencies and even multifrequency testing can yield different results.

As mentioned earlier, the classical tympanometric shape descriptions often lack the objectivity desired. The qualitative nature of this tympanometric shape classification can lead to some subjectivity in the differentiation of type A tympanograms from type A_S or type A_D. In the presence of an extremely shallow peak, classifying a tympanogram as type A_S or B can become a judgment call for many clinicians. While the classical descriptions of tympanometric shape will likely remain popular for some time, growing numbers of audiologists favor a more quantitative method of tympanometric classification that lends a greater objectivity to this important component of the overall hearing assessment. Such classification relies on measures of tympanometric peak pressure (TPP), tympanometric height (static **acoustic admittance** or compliance) and calculation of tympanometric width (TW), measures that are automatically calculated on most modern immittance meters (Table 7.1).

Acoustic Reflexes

Definition of the Acoustic Reflex

Two small muscles, the **tensor tympani muscle** and the **stapedius muscle**, are involved in the operation of the middle-ear mechanism. The anatomy of these muscles is discussed in Chapter 10, but they are mentioned here because their action makes them an important part

of the immittance battery. Although there is uncertainty about the role of the tensor tympani in response to sound in humans, it is generally accepted that the stapedius muscle contracts reflexively in response to intense sound, causing the tympanic membrane to stiffen. This has been called the acoustic reflex. Most normal-hearing individuals will demonstrate a bilateral **intra-aural muscle reflex** when pure tones are introduced to either ear at 85 to 100 dB SPL (Gelfand, 2002).

Measuring the Acoustic Reflex

The immittance meter enables the clinician to present a signal to one ear and detect a decrease in tympanic membrane compliance in either that ear (the ipsilateral acoustic reflex) or the opposite ear (the contralateral acoustic reflex). The signal used to produce the acoustic reflex is called the **reflex-activating stimulus (RAS)**, which can be any kind of sound from a pure tone to a noise band. Normally, pure tones sampling the frequency range from 500 to 4000 Hz are used. A pure tone of the desired frequency should be introduced at 70 dB HL. If no compliance change is seen on the meter, the level should be raised to 80 dB, 90 dB, and so on, until a response is seen or the limit of the equipment is reached. Some commercial meters allow intensities up to 125 dB HL to be tested, but great care should be taken in introducing signals at such high levels. It is often inadvisable to exceed 115 dB HL.

If a response is observed, the level should be lowered 10 dB, then raised in 5 dB steps until the threshold can be determined. The tonal duration should be about one second, and measurements should be taken that sample the frequency range—for example, 500, 1000, 2000, and 4000 Hz; however, for no explainable reason, many normal-hearing individuals show no acoustic reflex at 4000 Hz. The lowest level at which an acoustic reflex can be obtained is called the **acoustic reflex threshold (ART)**.

Criteria for the amount of compliance decrease required to constitute a response vary with different devices. At times a very small compliance change is observed, and the audiologist may be uncertain whether a response has truly been obtained. In such cases, when the level is raised 5 dB, an unequivocal response is usually observed. Extraneous compliance variations sometimes occur as the patient breathes, or occasionally the very sensitive probe microphone picks up a pulse from a blood vessel near the external ear canal. Of course, the patient must be completely silent during these measurements lest vocalizations be picked up by the microphone, masking changes in compliance. Proper recording of the intensity required to evoke a contralateral acoustic reflex assists in appropriate interpretation of results (Figure 7.4b).

Clinical Commentary

While speech-language pathology and audiology are separate professions with independent scopes of practice, some services overlap between the professions. According to ASHA's Board of Ethics (ASHA, 2004), speech-language pathologists may screen for middle-ear pathology for the purpose of referral for further evaluation and management. A normal tympanogram accompanied by a present acoustic reflex indicates normal middle-ear function. According to the Board, judgments and descriptive statements about immittance screening results should be limited to whether an individual has passed the screening.

Implications of the Acoustic Reflex

To understand the implications of acoustic reflex testing, it is important to have a basic knowledge of what is called the **acoustic reflex arc**. This pathway includes centers that are discussed in greater detail in Chapters 10 through 12 of this book, but they are mentioned here and diagrammed in Figure 7.6.

6. The cranial nerves involved with the acoustic reflex are _____ and _____.

A sound presented to the outer ear is passed through the middle ear as mechanical energy, transduced to an electrochemical signal in the cochlea of the inner ear, and then conducted along the VIIIth cranial (auditory) nerve to the brain stem. The impulse is received by the cochlear nucleus in the brain stem and is transmitted to the superior olivary complex. Here, some very interesting things occur: In addition to transmitting signals to higher centers in the brain (not shown in Figure 7.6), nerve impulses are sent from the superior olivary complex to the VIIth cranial (facial) nerve on the same side of the head, which in turn descends to innervate the stapedius muscle in the middle ear that originally received the sound, assuming that all systems are working properly. This is called the *ipsilateral response pathway*. In short, a sound presented to one ear can evoke an acoustic reflex in the same ear.

Almost simultaneously, neural impulses cross the brain stem to the opposite (contralateral) superior olivary complex, which in turn sends impulses by that facial nerve to the middle ear on the

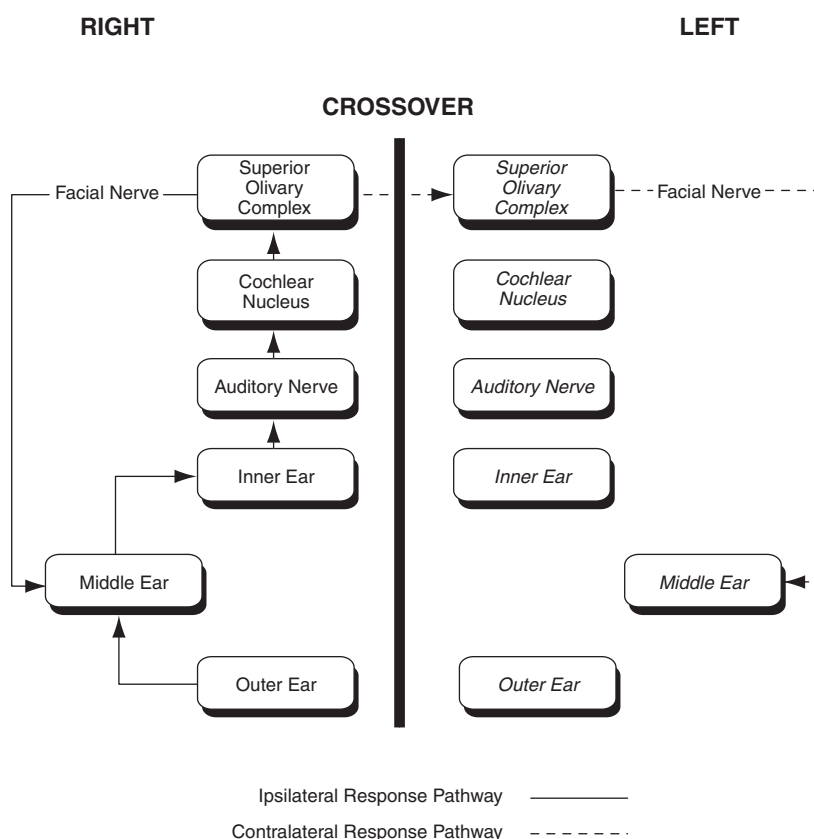


FIGURE 7.6 Block diagram of the ipsilateral and contralateral acoustic reflex pathways.

other side to evoke an acoustic reflex along the *contralateral response pathway*. Therefore, a stimulus presented to one ear evokes an acoustic reflex in the opposite middle ear as well as in the same ear. Although measurement of the acoustic reflex is made clinically in one ear at a time, in healthy ears, and in some pathological cases, responses occur in both ears in response to a stimulus presented to only one ear. Measurements are always made through the probe tip; however, the RAS may be presented through an earphone coupled to the ear opposite the probe assembly (the contralateral reflex), or through the probe tip itself (the ipsilateral reflex) (Figure 7.3). The measurement of ipsilateral and contralateral reflexes is extremely valuable in audiological diagnosis.

There are four possible outcomes on an acoustic reflex test:

1. The reflex may be present at a normal sensation level (about 85 dB SL).
2. The reflex may be absent at the limit of the reflex activating system (usually 110 to 125 dB HL).
3. The reflex may be present, in the case of a hearing loss, but at a low sensation level (less than 60 dB above the audiometric threshold).
4. The reflex may be present, but at a high sensation level (greater than 100 dB above the audiometric threshold).

7. Assuming normal hearing in both ears, a reflex-activating signal presented in the left ear will elicit a reflex in the right ear, left ear, or both ears?

Interpreting the Acoustic Reflex

Significance is placed on the presence or absence of the intra-aural muscle reflex and on the level of the RAS above the audiometric threshold (Figures 7.4b and 7.4d) required to elicit the response. Abnormalities in the muscles themselves will, of course, affect the reflex in the ear to which the probe is affixed. In addition, the contraction of the muscles may not result in tympanic membrane stiffening if the chain of bones in the middle ear is immobile or interrupted, or if fluid is present in the middle-ear space.

The portion of Figure 7.4 provided for the recording of acoustic reflex results is exaggerated in the diagram in Figure 7.7 to simplify the concepts of ipsilateral and contralateral stimulation since these concepts are frequently confusing to students.

Table 7.2 illustrates theoretical findings on acoustic reflex tests with ten possible conditions of the auditory and related systems. In each (lettered) example the condition is stated and the patients appear facing the reader as they would with the audiometer earphone attached to the right ear and the immittance meter probe in the left, and then with the earphone attached to the left ear and the probe in the right. During contralateral stimulation in each case the earphone delivers the RAS to one ear while the reflex is monitored via the probe in the opposite ear. During ipsilateral stimulation the RAS is delivered and monitored by the probe in the same ear. There are, of course, many other possibilities in addition to those shown below, and different constellations of responses may be attributed to a number of factors.

1. Middle-ear muscle reflexes will be present at about 85 dB SL in normal-hearing individuals (Table 7.2A).
2. The middle-ear muscle reflex will be absent if the reflex activating tone presented to the cochlea is not sufficiently intense. The intensity of the tone will be attenuated if any of several types of hearing losses are present, especially those caused by conductive lesions (Table 7.2B, 7.2C).
3. Sometimes the reflex appears in an ear with a hearing loss when the stimulus is presented at a fairly low sensation level. For example, a 50 dB hearing loss may show a reflex at 95 dB HL (45 dB SL). A precise explanation for low-sensation-level acoustic reflexes,

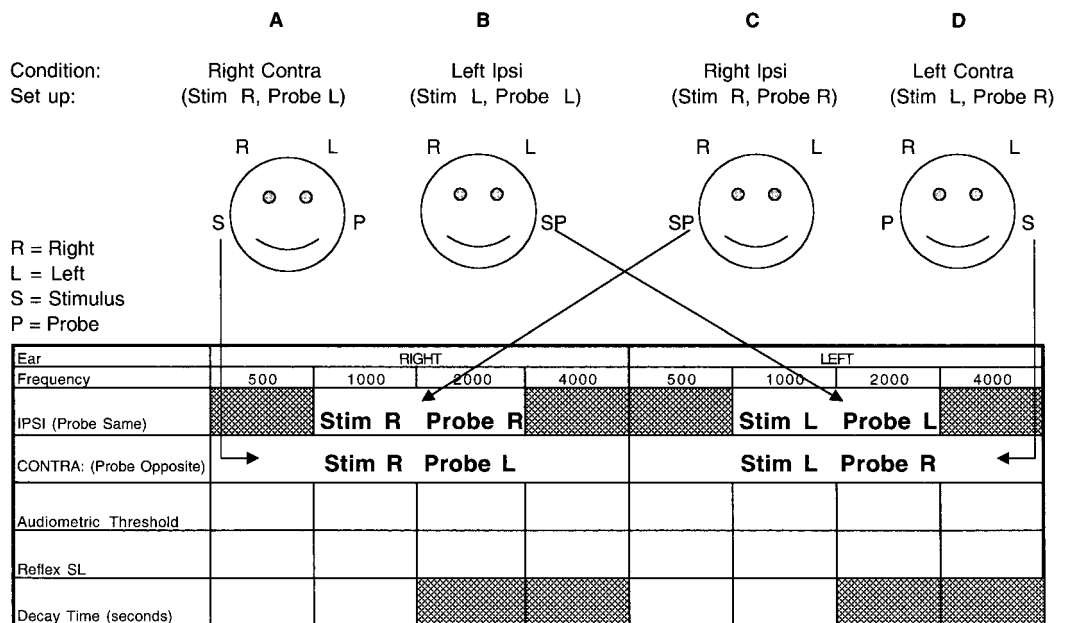


FIGURE 7.7 The portion of the acoustic immittance form (Figure 7.4) used for recording acoustic reflexes. Acoustic reflex thresholds (ARTs) obtained using pure tones as the reflex activating signals (RASs) as well as the sensation levels (SLs) of the ARTs are recorded as follows:

- Right contralateral ARTs with the RAS presented to the right ear through an earphone placed on the right ear and the reflex monitored through the probe in the left ear. The SLs of the ARTs for the right ear are obtained by subtracting the voluntary audiometric thresholds obtained in the right ear from the right ear contralateral ARTs at 500, 1000, 2000, and 4000 Hz.
- Left ipsilateral ARTs with the RAS presented to the left ear through the probe and the reflex monitored through the same probe. Frequencies tested are 1000 and 2000 Hz.
- Right ipsilateral ARTs with the RAS presented to the right ear through the probe and the reflex monitored through the same probe. Frequencies tested are 1000 and 2000 Hz.
- Left contralateral ARTs with the RAS presented to the left ear through an earphone placed on the left ear and the reflex monitored through the probe in the right ear. The SLs of the ARTs for the left ear are obtained by subtracting the voluntary audiometric thresholds obtained in the left ear from the left ear contralateral ARTs at 500, 1000, 2000, and 4000 Hz.

which are associated with cochlear lesions, is lacking at this time (Table 7.2D, 7.2E). Since behavioral auditory thresholds are not obtained through the probe of an immittance device the sensation levels using ipsilateral stimulation cannot be determined. The examples in Table 7.2 therefore are hypothetical.

- When a severe cochlear hearing loss exists in the ear that receives the RAS, there will often be no response at the limit of the equipment (Table 7.2F). This is because the intensity of the signal reaching the brain stem is insufficient to produce the reflex.
- When there is damage to the auditory (VIIIth cranial) nerve, acoustic reflexes are frequently absent, occur at higher-than-normal sensation levels, or the amplitude of the reflex is less than normal. This is probably due to alterations in the transmission of the RAS from the cochlea to the brain stem (Table 7.2G).
- The facial nerve supplies innervation to the stapedius muscle. If the facial nerve is in any way abnormal, the command supplied by the brain that mediates contractions may not be conveyed to the stapedius muscle. This occurs when the damage is on the side of the head to which the probe is affixed, regardless of whether the RAS is delivered ipsilaterally or contralaterally (Table 7.2H).

TABLE 7.2 Theoretical Examples of the Results of Ipsilateral and Contralateral Acoustic Reflex Testing for Ten Different Conditions (Key: HL = hearing loss, SL = sensation level, SPL = sound-pressure level)

		<i>Right Contralateral</i>	<i>Left Ipsilateral</i>	<i>Right Ipsilateral</i>	<i>Left Contralateral</i>
		<i>Phone Right Probe Left</i>	<i>Phone Right Probe Left</i>	<i>Phone Left Probe Right</i>	<i>Phone Left Probe Right</i>
A	Right - Normal Hearing	Present at	Present at	Present at	Present at
	Left - Normal Hearing	Normal SL	Normal SL	Normal SL	Normal SL
B	Right - Normal Hearing	Absent	Absent	Present at	Absent or
	Left - Conductive HL			Normal SL	Present at High SPL
C	Right - Conductive HL	Absent	Absent	Absent	Absent
	Left - Conductive HL				
D	Right - Normal Hearing	Present	Present at	Present at	Present at
	Left - Cochlear HL	at Normal SL	Low SL	Normal SL	Low SL
	(mild to moderate)				
E	Right - Cochlear HL	Present at	Present at	Present at	Present at
	(mild to moderate)	Low SL	Low SL	Low SL	Low SL
	Left - Cochlear HL				
	(mild to moderate)				
F	Right - Cochlear HL (severe)	Absent	Absent	Absent	Absent
	Left - Cochlear HL (severe)				
G	Right - VIIIth N. HL	Absent or	Present at	Absent or	Present at
	(mild to moderate)	Present at	Normal SL	Present at	Normal SL
	Left - Normal Hearing	High SPL		High SPL	
H	Right - Normal Hearing	Present at	Present at	Absent	Absent
	(VIIIth nerve lesion)	Normal SL	Normal SL		
	Left - Normal Hearing				
I	Right - Normal Hearing	Absent	Present at	Present at	Absent
	Left - Normal Hearing		Normal SL	Normal SL	
	(brain-stem lesion)				
J	Right - Normal Hearing	Present at	Present at	Present at	Present at
	(cortical lesion)	Normal SL	Normal SL	Normal SL	Normal SL
	Left - Normal Hearing				

7. Even if the ipsilateral acoustic reflex pathway is normal, if damage occurs in the areas of the brain stem that house portions of the contralateral acoustic reflex pathway, ipsilateral reflexes may be present in both ears, but one, or more commonly both, of the contralateral reflexes will be absent (Table 7.2I).
8. Lesions in the higher centers of the auditory cortex usually produce no abnormalities in either contralateral or ipsilateral reflexes because these centers are above the acoustic reflex arc (Table 7.2J).

The acoustic reflex portion of the immittance test battery can also serve as an important cross-check of findings in a pediatric evaluation or as an indication of normal hearing or potential hearing loss in otherwise difficult-to-test patients as discussed in Chapter 12. This **sensitivity prediction from the acoustic reflex** test (Jerger, Burney, Maudlin, & Crump, 1974), based upon a comparison of the acoustic reflex threshold (ART) for pure tones to the ART for broadband noise, does not reveal actual hearing thresholds, but helps to categorize the patient as either having normal hearing or greater than a 30 dB sensory/neural hearing loss.

8. Acoustic reflex thresholds of patients with cochlear hearing losses are expected to occur at _____ sensation levels.

Acoustic Reflex Decay Test

When the stapedius muscle is contracted by an intense sound in normal-hearing individuals, it will gradually relax as it is constantly stimulated. This is called **acoustic reflex decay**, and it is normal in the higher frequencies; however, significant amounts of decay in the low frequencies are usually seen only in lesions of the auditory nerve and some parts of the brain stem. Reflex decay is measured by sustaining a tone at 10 dB above the ART and determining the number of seconds required for the amplitude of the reflex (the compliance change) to be reduced by 50%. The test is completed when the reflex has decayed to half its original amplitude, or at the end of 10 seconds, whichever occurs first.

Recording and Interpreting Acoustic Reflex Decay Test Results. This test is scored according to the number of seconds required for the amplitude of the reflex to decay to half magnitude. Test results may be printed automatically on a graph, so that changes in the amplitude of the response can be observed as a function of time, or they may be recorded on a form such as the one shown in Figure 7.4e.

In subjects with normal hearing there will be some decay of the reflex at 2000 and 4000 Hz, but not at 500 and 1000 Hz, so this test is not performed in the higher frequencies. The slight decay sometimes evident in patients with cochlear hearing losses tends to occur more in the higher frequencies. Lesions in the auditory nerve cause decay to half the original magnitude of the reflex, often within three to five seconds, even at 500 Hz (Anderson, Barr, & Wedenberg, 1970) because the nerve cannot maintain its continuous firing rate. Because the primary innervation of contraction of the middle-ear muscles is by way of the descending tract of the facial nerve, damage to that nerve may also cause an absent acoustic reflex or an initial response followed by rapid acoustic reflex decay.

If contralateral acoustic reflexes and reflex decay are normal or provide information that confirms the audiometric findings, there is often no necessity to perform ipsilateral reflex testing, although such elimination saves very little time. However, many times contralateral testing is inconclusive or cannot be carried out at all. In such cases tests can be done ipsilaterally; however, it should be noted that slightly different results might be found (Oviatt & Kileny, 1984) for acoustic reflex decay. When abnormal patterns are observed, a comparison of ipsilateral and contralateral tests can help to isolate lesions in the ascending tract versus the descending tract (Table 7.2).

Clinical Commentary

Immittance measures should be among the first tests performed on a patient. Not only does this practice arm the audiologist with knowledge of what might be expected from pure-tone tests, under certain conditions bone-conduction audiometry may be unnecessary when acoustic immittance measures are viewed in light of other audiometric procedures. In the presence of normal hearing for pure tones, high word-recognition scores, normal tympanograms, and normal acoustic reflex thresholds, normal hearing may be diagnosed without performance of bone conduction. When air-conduction thresholds are depressed, tympanometry is normal, and acoustic reflexes are present, conductive hearing loss is eliminated as a possible finding, and bone-conduction audiometry will provide no further insights toward a diagnosis of sensory/neural hearing loss. If any signs of conductive loss do appear, such as absent acoustic reflexes or abnormal tympanograms, bone-conduction audiometry must be carried out to ascertain the degree of any air-bone gap. Unfortunately, these are usually the times when bone-conduction measures are least straightforward due to complications presented by middle-ear artifacts and masking (i.e., in those with conductive and mixed hearing loss).

9. Extremely rapid acoustic reflex decay is expected of patients with lesions of the _____.

Otoacoustic Emissions (OAE)

The fact that many normal cochleas are capable of producing sounds in the absence of external stimulation came as a surprise to researchers and clinicians in audiology when it was first described by Kemp in 1979. These **spontaneous otoacoustic emissions (SOAEs)** occur in over half the population of persons with normal hearing as a continuous tonal signal that can be recorded in the external auditory canal. The typical frequency range of an SOAE is 1000 to 3000 Hz, although some have been reported well above and below this range. While there is considerable variation in the amplitude of an SOAE, it is often found to be between -10 and $+10$ dB SPL and is generally inaudible to the person in whom it is measured. It is possible to have more than one SOAE in a given ear and to have otoacoustic emissions in both ears. The physiological basis of these sounds is discussed in Chapter 11.

A second class of OAEs occurs either during or immediately following acoustic stimulation. These responses are called **evoked otoacoustic emissions (EOAEs)**, and there are several types. The use of EOAE testing has come into clinical prominence in the differential diagnosis of sensory/neural hearing loss, hearing screenings of infants and other difficult-to-test patients, and the monitoring of outer hair cell function of patients particularly susceptible to the damaging effects of high-level noise exposure or ototoxic medications. In many places, application of EOAE has become the standard of care in pediatric practice (Lonsbury-Martin & Martin, 2003). In addition to the current uses of EOAE, we can expect the role of this measure to increase in the decades ahead as new protective and restorative treatments are developed for use with sensory/neural hearing impairment (Kemp, 2002). The two major types of EOAE are transient and distortion-product emissions.

10. Otoacoustic emissions may be either spontaneous or _____.

Transient-Evoked Otoacoustic Emissions (TEOAEs)

Transient-evoked otoacoustic emissions (TEOAEs) are produced by brief acoustic stimuli, such as clicks or tone pips. Signal-averaging equipment, similar to that described in the section on auditory-evoked potentials (to follow), must be used to separate the emission from ongoing noise in the ear. Anywhere from 260 to 500 stimuli are presented, and the waveforms of the responses are averaged, along with the ongoing noise in the ear, in order to improve the signal-to-noise ratio (SNR). Responses should be observable from virtually all individuals with normal outer, middle, and inner ears. As hearing loss due to cochlear damage increases, the amplitude of the response decreases until a hearing loss of about 40 dB, where the response usually disappears altogether.

When a click stimulus is used, a wide area of the cochlea is stimulated and a broad range of frequencies is normally present in the TEOAE. If a broadband TEOAE can be observed, it may be inferred that the pathway up to the cochlea, the auditory periphery, is unimpaired. It cannot be known whether there is a disorder in the auditory nerve or other structures beyond the cochlea. Therefore, a normal TEOAE does not guarantee normal hearing. When a TEOAE is not seen, the suggestion is that a hearing loss is present, but does not reveal whether the problem is in the conductive pathway or the cochlea. A commercial version of an OAE measurement device can be seen in Figure 7.8, and a typical response is shown in Figure 7.9. Documentation of TEOAE results for a normal-hearing individual is shown in Figure 7.14.

11. True/False
 A normal TEOAE does not guarantee normal hearing, and an absent TEOAE does not tell whether the loss is conductive or sensory/neural.



FIGURE 7.8 Commercial device for measurement of otoacoustic emissions, sounds generated by the cochlea indicative of cochlear function. (Courtesy of Grason-Stadler Co.)

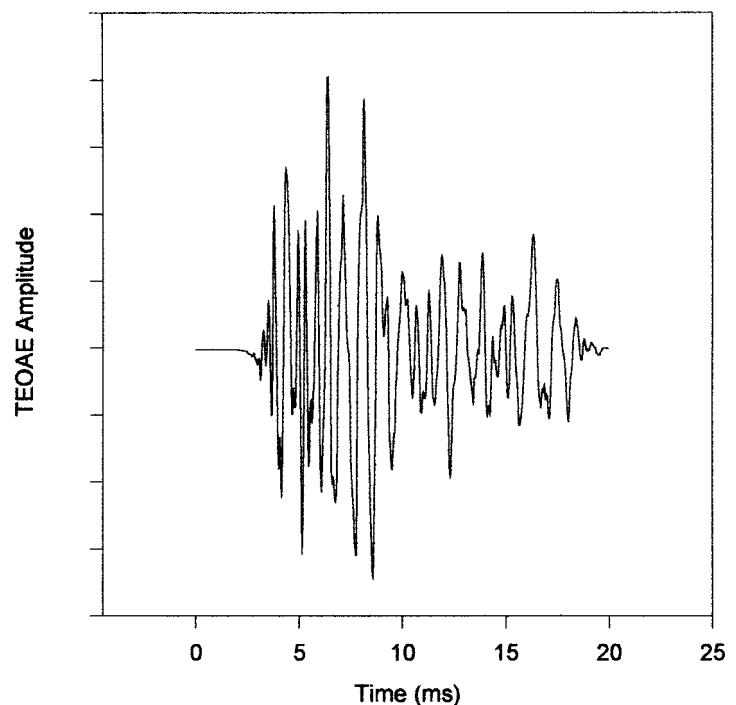


FIGURE 7.9 A typical transient-evoked otoacoustic emission.



For a demonstration of how to test for OAEs, see the video titled “Otoacoustic Emissions” in the Clinical Demonstrations section on the Companion Website.

Distortion-Product Otoacoustic Emissions (DPOAEs)

When two “primary tones” that vary in frequency by several hundred hertz (F_1 and F_2 , where $F_2 > F_1$) are presented to the ear, the normal cochlea responds by producing energy at additional frequencies. These are called **distortion-product otoacoustic emissions (DPOAEs)**. By varying the primary-tone frequencies, responses are generated from different areas of the cochlea. Typically, the levels and the frequency ratio of the primary tones are not varied. These responses often

compare favorably with voluntary audiometric results, provided that the hearing loss does not exceed 40 to 50 dB. As with TEOAEs, the conductive pathway must be normal to obtain DPOAEs.

Measuring OAEs

Advances in microcircuitry have allowed for accurate measurement of OAEs. A probe is placed in the external auditory canal that contains a miniature loudspeaker to present the evoking stimulus and also a tiny microphone to pick up the emission and convert it from a sound into an electrical signal. The device that delivers the stimuli for DPOAE testing differs from the one for measuring TEOAEs, in that the probe that is fitted to the ear must have two openings (ports) that can deliver the two primary tones. Because DPOAEs are separate in frequency from the evoking stimuli, averaging background noise is less of a problem for measurement of DPOAEs than for TEOAEs, and fewer stimulus presentations are required, which may reduce test time slightly. Acoustic control of the test environment for OAE testing is less critical than might be imagined, since the noise that must be averaged out is the noise contained in the ear of the subject. If subject noise levels are too high, for example, in crying babies, they may mask the emission, since the sensitive microphone used cannot differentiate one acoustic signal from another.

Interpreting OAEs

Otoacoustic emissions reflect the activity of an intact cochlea, and a brief physiological explanation of this phenomenon can be found in Chapter 11 on the inner ear. For any type of OAE to be observed, the conductive pathway must be normal, because the strength of a signal traveling from the inner ear to the outer ear canal may be attenuated by an abnormality of the middle ear in the same way as an externally generated signal traveling from the outer ear to the inner ear.

The presence of an EOAE suggests that there is very little or no conductive hearing loss caused by middle-ear abnormality. It further suggests that responding frequency regions of the cochlea are normal, or exhibit no more than a mild hearing loss. If OAEs are present in sensory/neural hearing loss, then outer-hair-cell function is intact and the locus of the disorder is known to be retrocochlear. Absent OAEs in the presence of sensory/neural hearing loss confirm cochlear pathology but do not rule out the possibility of concomitant retrocochlear involvement. The result is that OAE measures allow for improved diagnostic differentiation among the different types of hearing losses (Prieve & Fitzgerald, 2009).

12. A patient with a severe sensory/neural hearing loss with normal otoacoustic emissions is expected to have a lesion of the _____.

Clinical Commentary

In the 1990s otoacoustic emissions measures brought new insights and diagnostic capabilities to clinical audiology just as the advent of acoustic immittance measures did in the 1970s. In addition to the use of transient-evoked otoacoustic emissions to help differentiate sensory from neural hearing losses, in the absence of peripheral pathology, distortion-product otoacoustic emissions can establish normal, or near-normal, hearing in a difficult-to-test child or a patient manifesting erroneous response behaviors (Chapter 13). Otoacoustic emissions have found a prominent place in the hearing screening of newborns, as discussed in Chapter 8, and in the monitoring of cochlear function when potentially ototoxic medications are used to combat illness. As discussed in Chapter 12, research continues into the interactions of the TEOAE and stimulation of the contralateral ear with acoustic competition as potentially useful in assessment of central auditory function as well.

Laser-Doppler Vibrometer Measurement

Just as acoustic immittance measures and otoacoustic emissions evolved from the research laboratory to regular clinical use, so may the use of Laser-Doppler Vibrometer (LDV) measurements. This promising tool measures the sound-induced velocity of the tympanic membrane near the umbo and may prove to be a sensitive tool for the differential diagnosis of ossicular disorders that surpasses the current utility of acoustic immittance (Rowsowski, Nakajima, & Merchant, 2008). This tool may also prove useful in differentiating between air-bone gaps secondary to ossicular fixations and those air-bone gaps that may be observed with some inner-ear malformations. While it may yet be a few years before this emerging tool is routinely used in audiology clinics, it holds promise for providing greater powers of noninvasive differential diagnoses for audiologists.

Auditory-Evoked Potentials

From the time acoustic stimuli reach the inner ear, what is transmitted to the brain is not “sound” but rather a series of neuroelectric events. For many years there has been considerable interest in the measurement of the electrical responses generated within the cochlea to establish an objective measure of hearing sensitivity in infants and other persons who are unable to participate in behavioral audiometric tests. To this end, a procedure has evolved called **electrocochleography (ECoG)**. Additionally, because hearing is a phenomenon involving the brain, it is only logical that whenever a sound is heard, there must be some change in the ongoing electrical activity of the brain. These electrical responses, which may be recorded from the scalp using surface electrodes, have been referred to by several names, but today they are commonly known as **auditory-evoked potentials (AEP)**. AEPs can be subdivided on the basis of where and when they occur. They are better understood with the background provided in Chapter 12, which briefly reviews the auditory nervous system. Before attempting to measure an AEP, much more auditory anatomy and physiology, as well as other aspects of neuroscience, should be known than can be presented in an introductory text.

In Chapter 2, some mention was made of the connections between the brain stem and the higher centers for audition in the cerebral cortex. These connections occur via a series of waystations, called nuclei, within the central nervous system. When a signal is introduced to the ear, there are immediate electrical responses in the cochlea. As the signal is propagated along the auditory pathway, more time elapses before a response occurs, and thus the signal can be recorded at each subsequent nucleus in the pathway. The term **latency** is used to define the time period that elapses between the introduction of a stimulus and the occurrence of the response. The term **amplitude** is used to define the strength, or magnitude, of the AEP.

Early AEPs, those that occur in the first 10 to 15 milliseconds after the introduction of a signal, are believed to originate in the VIIIth cranial nerve and the brain stem and are called the **auditory brain-stem responses (ABR)**. An AEP occurring from 15 to 60 milliseconds in latency is called the **auditory middle latency response (AMLR)** and originates in the cortex. Those called the **auditory late responses (ALR)**, or cortical auditory-evoked potentials, occur between 50 to 200 milliseconds and presumably arise in the cortex. Responses recorded between 220 and 600 milliseconds have been called **auditory event-related potentials (ERP)** (or P300) because they are contingent on some auditory event occurring within a particular context of sound sequence and involve association areas in the brain.

An AEP is simply a small part of a multiplicity of electrical events measurable from the scalp. This electrical activity, which originates in the brain, is commonly referred to as electroencephalic and is measured on a specially designed instrument called an **electroencephalograph (EEG)**, which

is used to pick up and amplify electrical activity from the brain by electrodes placed on the scalp. When changes in activity are observed on a computer monitor or printout, waveforms may be seen that aid in the diagnosis of central nervous system disease or abnormality.

In coupling the EEG to a patient to observe responses evoked by sounds, the ongoing neural activity is about 100 times greater than the auditory-evoked potential and therefore obscures observation of the AEP. The measurement of AEPs is further complicated by the presence of large electrical potentials from muscles (myogenic potentials). These obstacles were insurmountable until the advent of averaging computers, devices that allow measurement of electrical potentials, even when they are embedded in other electrical activity. A commercial device for measuring AEP is shown in Figure 7.10.

To measure an AEP, a series of auditory stimuli is presented to the subject at a constant rate by a transducer (earphone, bone-conduction vibrator, or loudspeaker). Insert earphones are becoming the standard for AEP testing (as well as behavioral testing) because they are relatively comfortable to wear and help attenuate extraneous room noise. Also, their transducers are 250 millimeters from electrodes placed at the ear and therefore produce fewer electrical artifacts. The EEG equipment picks up the neural response, amplifies it, and stores the information in a series of computer memory time bins. Each bin sums neuroelectric activity that occurs at specific numbers of milliseconds after the onset of the stimulus. Of course, the computer is summing not only the response to the sound in any particular time bin, but also the random brain activity taking place at that precise moment. However, because the random activity consists of positive and negative voltages of varying amplitudes, summing reduces them to a value at or near zero. The polarity of the neural response is either positive or negative but not both. Summing alone would cause the amplitude of the response to increase, but the waveform is then averaged by dividing the amplitude by the number of signal presentations. This decreases the summed response to the amplitude of the averaged response. While there is no increase in amplitude of the AEP, there is a decrease in the amplitude of the random noise as it is summed and averaged. It might be said that



FIGURE 7.10 Device used for recording auditory-evoked potentials, electrical responses to sound that are generated within the cochlea and measured through changes in the ongoing electrical activity of the brain. (Courtesy of Natus Medical Incorporated.)

as the summing and averaging process continues the signal-to-noise ratio improves. Even though the amplitudes of the responses are extremely small, often on the order of 1 to 5 microvolts (1 μ V is equal to one-millionth of a volt), they can nevertheless be detected and interpreted.

Electrocochleography (ECoG)

The procedure for measuring electrical responses from the cochlea of the inner ear is called electrocochleography (ECoG, or sometimes ECochG). An active electrode may be placed in one of several positions, ranging from surgical placement of the electrode on the promontory, the medial wall of the middle ear, to less invasive placements within the outer ear canal. The further the active electrode is from the inner ear, the smaller the amplitude of the response and, consequently, the greater the number of stimuli that must be summed before the response can be identified with confidence.

13. ECoG has been found to be useful during _____.

The decision on whether to use more- or less-invasive electrodes during ECoG is largely determined by the types of workplaces in which audiologists find themselves, since all methods have their advantages and disadvantages (Ferraro, 1992). Transtympanic approaches, necessitating penetration of the tympanic membrane, are usually carried out in settings where physicians are on site since anesthesia is required. Extratympanic procedures, not requiring the risk or discomfort of minor surgery, can be performed in virtually any audiological setting although greater signal averaging is required to obtain a clear signal as the electrode is moved further from the promontory. Clinicians turned to the ABR as the electrophysiologic measure of choice in the mid 1970s largely because of the invasiveness of the conventional transtympanic electrode (Hall, 2007). The primary focus for ECoG testing has moved from the determination of auditory sensitivity in difficult-to-test individuals (Cullen, Ellis, Berlin, & Lousteau, 1972) to neuro-otological applications, such as monitoring the function of the cochlea during some surgical procedures, enhancing the results of other electrophysiological tests, and probably most important, assisting in the diagnosis and monitoring of some conditions of the inner ear, such as Ménière’s disease (see Chapter 11).

Auditory Brain-Stem Response (ABR) Audiometry

For measuring responses from the brain, electrodes are usually placed on the mastoid process behind the outer ear and the vertex (top of the skull), with a ground electrode placed on the opposite mastoid, the forehead, or the neck. Stimuli with rapid rise times, such as clicks, must be used to generate these early responses. Tone pips, or bursts, which provide some frequency-specific information, can be used. When a summing computer is used, seven small wavelets generally appear in the first 10 milliseconds after signal presentation. Each wave represents neuroelectrical activity at one or more generating sites along the auditory brain-stem pathway. The findings of Legatt, Arezzo, and Vaughan (1988) indicate the following simplified scheme of major ABR generators:

Wave Number	Site
I	VIIIth cranial nerve
II	VIIIth cranial nerve
III	Superior olivary complex
IV	Pons, lateral lemniscus
V	Midbrain, lateral lemniscus, and inferior colliculus
VI and VII	Undetermined



FIGURE 7.11 Within an acoustically isolated and electrically shielded room a patient is seated in a comfortable chair to encourage relaxation during ABR testing.

There are several ways in which routine ABR audiometry is performed, only one of which is described here. The patient is first seated in a comfortable chair, often a recliner, which is placed in an acoustically isolated, electrically shielded room (Figure 7.11). The skin areas to which electrodes will be attached are carefully cleansed, and a conductive paste or gel is applied to the area. One electrode is placed on the vertex or the forehead and one on each earlobe or the mastoid process behind the external ear. An electrode opposite the ear being tested serves as a **ground**. After the electrodes are taped in place, electrical impedance is checked with an ohmmeter. The impedance between the skin and the electrodes, and between any two electrodes, must be controlled for the test to be performed properly. An insert receiver is placed into the test ear, or a circumaural earphone is placed over the test ear, and the patient is asked to relax. The lights are usually dimmed, and the chair placed in a reclining position. The ABR is not affected by sleep state; therefore, the subject may sleep while the responses are being recorded. This characteristic of the ABR is important because it allows anesthetized or comatose individuals to be evaluated.

14. A summing computer is used in ABR testing to help identify 7 small wavelets within the first _____ msec of the stimulus.

For a demonstration of patient preparation and recording of the ABR, see the video titled "Auditory Brainstem Response" in the Clinical Demonstrations section on the Companion Website.



One ear is tested at a time. A series of 1000 to 2000 clicks may be presented at a rate of 33.1 clicks per second. The click rate must not be one that is divisible by 1 with a resultant whole number in order to differentiate the real response from electrical artifacts in the room, such as the 60 Hz electrical current. The starting level is about 70 dB nHL (n is the reference to the normative group threshold for click stimuli).

In response to the stimulus, the ABR waveform appears as several narrow peaks and troughs within 1 to 10 ms of the signal onset. The main positive peaks are labeled, after Jewett (1970), in Roman numerals for Waves I, III, and V. If responses are not present, the intensity is raised 20 dB; if responses are present, the level is lowered in 10 or 20 dB steps until Wave V becomes undetectable. After the test has been completed, a hard copy may be printed out and these data may be summarized on a special form (see Figure 7.12). A complete ABR test will provide the following information about each ear:

1. Absolute latencies of all identifiable Waves I to V at different intensities
2. Interpeak latency intervals (i.e., I to V, I to III, III to V), or relative latencies
3. Wave amplitudes (absolute and relative)
4. Threshold of Wave V if hearing threshold estimation was the purpose of the test
5. A comparative response with a higher click rate (e.g., 91.1 clicks/second) if the ABR was for neurological assessment

The ABR has developed into the most important test in the diagnostic site-of-lesion battery and has proven to be sensitive, specific, and efficient in detecting lesions affecting the auditory pathways through the brain stem. While the standard ABR protocol has proven useful in detecting medium and large VIIIth nerve tumors, it has been augmented by the development of a clinical procedure known as the **stacked ABR** (Don & Kwong, 2009; Don, Masuda, Nelson, & Brackmann, 1997), which allows for identification of even very small (<1.0 cm) acoustic neuromas. This procedure is based on a division of the standard ABR whole-cochlea response into five frequency bands by using a high-pass noise-derived-response technique. The amplitudes of the five narrow-band responses are then “stacked,” or added, to give a measure of whole-nerve activity. A tumor affecting any portion of the auditory nerve will, therefore, yield a stacked ABR of smaller amplitude relative to the normal response. Thus, through the use of the stacked ABR procedure, auditory brain-stem response testing has become even more valuable to clinical audiology.

Interpreting the ABR. The ABR may be used as a test of audiological or neurological function. When testing to estimate behavioral hearing thresholds, as signal intensity decreases the wave amplitudes become smaller and latencies increase. Since Wave V normally has the largest amplitude of the first seven waves, the ABR threshold is considered to be the lowest intensity at

which Wave V can be observed. ABR threshold determinations can usually be ascertained to within 10 to 20 dB of behavioral thresholds. A comparison of ABR responses measured with air-conduction signals and bone-conduction signals is recommended when a conductive hearing loss is suspected.

The ABR may be used as a neurological screening test to assess the integrity of the central auditory pathway. The most significant finding in neurological lesions is an increase in the timing of one or more peaks in the response, indicating a slowing of the auditory response. This may be due to a tumor mass weighing on the nerve or nuclei, or possibly to other abnormal central-nervous-system disorders such as demyelinating diseases like multiple sclerosis. If Wave V can be observed at a slow click rate, for example, 11.1 clicks per second (often seen clearly

15. True/False
The ABR is a direct test
of auditory sensitivity.

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NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	INSTRUMENT

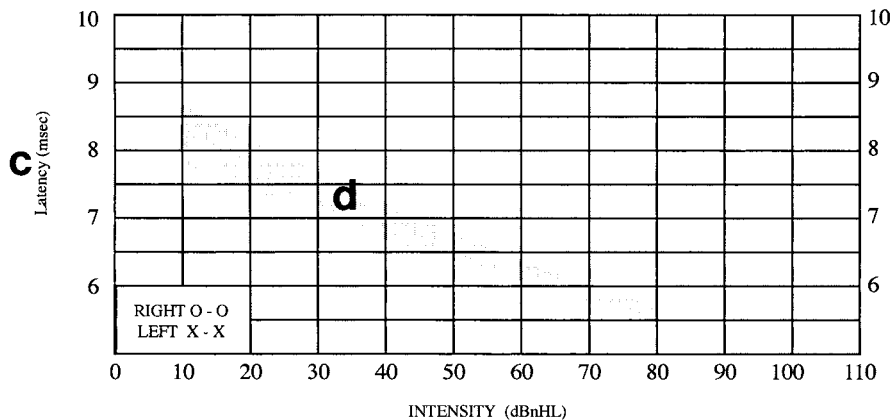
OTOACOUSTIC EMISSIONS
(Present or Absent)

a ☐ TEOAE Level _____
☐ DPOAE Level F₁ _____ F₂ _____

Right					Left				
500	1000	2000	4000	6000	500	1000	2000	4000	6000
b									

AUDITORY BRAINSTEM RESPONSE

ABR WAVE V LATENCY-INTENSITY FUNCTION



SHADED AREA REPRESENTS Normal Wave V Range for patients older than 16 mos. for 30 clicks per second

EAR	nHL		g Absolute Latency (ms)			h Interpeak Latency (ms)			i Latency Change w/ Increased Rate	
	dB HL	Click Rate	I	III	V	I-III	III-V	I-V	V	Click Rate
RIGHT	e	f								
LEFT										
Interaural Differences										

k
m

Amplitude Ratio (V same or > I) R _____ L _____
Estimated Air Conduction Threshold R _____ L _____
Estimated Bone Conduction Threshold R _____ L _____

FIGURE 7.12 Form used for recording results of otoacoustic emissions tests and auditory brain-stem responses.

- type of otoacoustic emissions test performed
- presence (P) or absence (A) of OAEs at five frequencies in each ear
- latency-intensity functions of ABR
- shaded area showing a normal distribution of Wave V latency values
- intensity (in dB nHL) required to evoke the response
- stimulus click rate
- absolute latencies for Waves I, III, and V
- interpeak latencies (in milliseconds) for Waves I-III, III-V, and I-V
- Wave V latency change (in milliseconds) due to increase in stimulus rate
- differences between the right and left ears for g-i
- amplitude ratio (Wave V same as or greater than Wave I)
- estimated air-conduction thresholds
- estimated bone-conduction thresholds

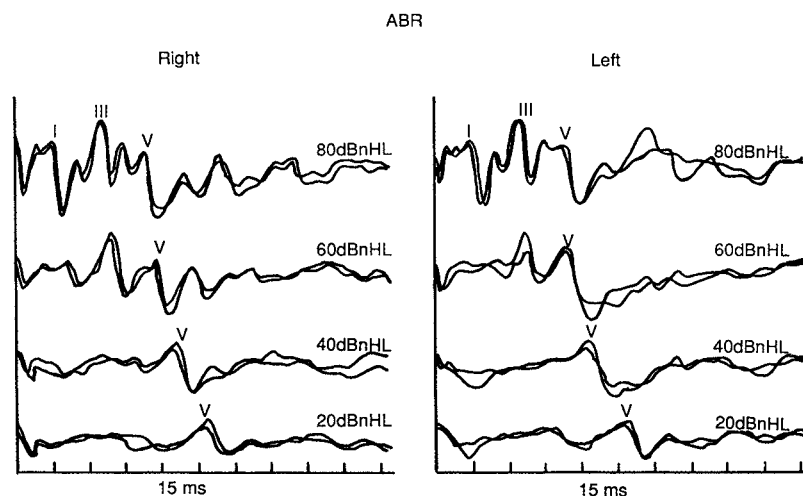


FIGURE 7.13 Auditory brain-stem response testing on a normal-hearing individual. Absolute latencies are shown in Figure 7.14.

at 70 dB nHL), a higher click rate may be presented, such as 89.1 clicks per second. An ABR is considered neurologically abnormal, indicating neuropathology affecting the auditory pathway of the brain stem, when any of the following occur:

1. Interpeak intervals are prolonged.
2. Wave latency is significantly different between ears.
3. Amplitude ratios are abnormal (normally Wave V is larger than Wave I).
4. Wave V is abnormally prolonged or disappears with high-click-rate stimulation.

Normal ABR results are shown in Figures 7.13 and 7.14.

Auditory Steady-State Response (ASSR)

The **auditory steady-state response (ASSR)**, also known as the steady-state evoked potential (SSEP), is another form of auditory-evoked potential and has proven useful in threshold determination for children. In addition, this procedure may prove to have certain advantages over tone-burst or click-evoked ABR.

As discussed in Chapter 8, the age at which hearing loss in children is identified has dropped considerably in recent years. As the age of identification of hearing loss decreases, the need for accurate and objective measures of determining hearing thresholds for newborns increases. Individualized remediation is enhanced with the advent of means to reliably uncover the degree, configuration, and type of hearing loss. While the use of the sensitivity prediction from the acoustic reflex (SPAR) test discussed earlier can be useful in categorizing degree of hearing loss, the variability among results limits its usefulness in accurately predicting threshold and the frequency-specific configuration of hearing loss. Otoacoustic emissions can provide frequency-specific information on the status of outer-hair-cell function but provide little information on the degree of hearing loss. Tone-evoked ABR testing can yield frequency-specific estimates of hearing loss, including degree, configuration, and type (using bone-conduction ABR testing) but can take considerable clinical time to complete. Reducing test time and obtaining the same results as the tone-evoked ABR may be possible using the ASSR technique. The ASSR is one of the latest tools to be added to the audiologist's arsenal to obtain reliable predictions of hearing sensitivity.

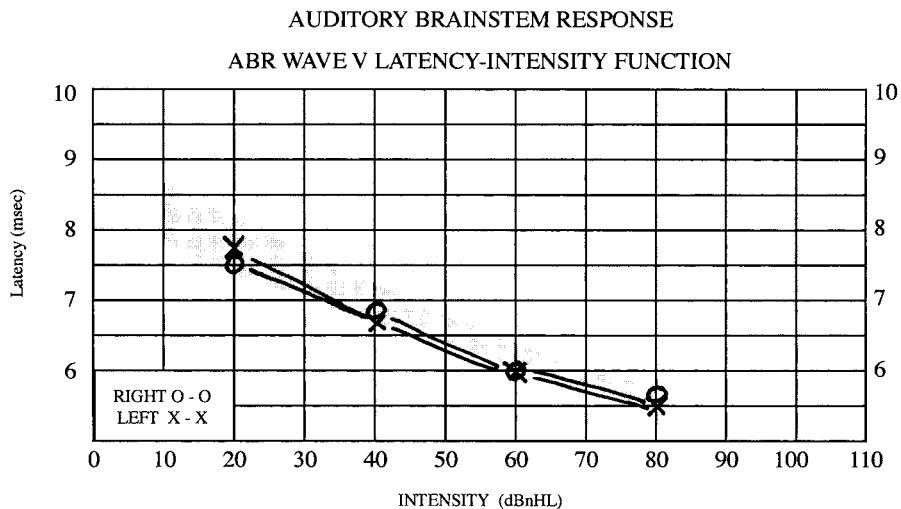
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NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	INSTRUMENT

OTOACOUSTIC EMISSIONS
(Present or Absent)

☒ TEOAE Level **80** dB Peak SPL
☐ DPOAE Level F₁ ____ F₂ ____

Right					Left				
500	1000	2000	4000	6000	500	1000	2000	4000	6000
P	P	P	P	P	P	P	P	P	P



EAR	nHL		Absolute Latency (ms)			Interpeak Latency (ms)			Latency Change w/ Increased Rate	
	dB HL	Click Rate	I	III	V	I-III	III-V	I-V	V	Click Rate
RIGHT	80	33.1	1.8	3.75	5.7	1.95	1.95	3.9		
LEFT	80	33.1	1.6	3.62	5.6	2.02	1.98	4.0		
Interaural Differences										

Amplitude Ratio (V same or > I) R NL L NL
 Estimated Air Conduction Threshold R ____ L ____
 Estimated Bone Conduction Threshold R ____ L ____

FIGURE 7.14 Documentation of results of objective hearing testing on a normal-hearing individual. Latency-intensity functions for Wave V are derived from the auditory brain-stem response tracings shown in Figure 7.13. All the latencies are normal. Transient-evoked otoacoustic emissions are marked as present.

While the tone-burst ABR and the ASSR provide similar estimates of behavioral pure-tone thresholds (Cone-Wesson, Dowell, Tolin, Rance, & Min, 2002), the investment of clinical time for testing can be considerably less for the ASSR. Importantly, the ASSR, like the ABR, is not affected by the patient's state of consciousness.

In addition to providing an estimate of auditory sensitivity, the ASSR can be employed to assess the efficacy of intervention through estimations of hearing thresholds in the sound field with and without hearing aids (Picton et al., 1998). These important measures for very young children who cannot overtly respond to test stimuli are not possible with tone-burst ABR measures given the distortions that can occur when short-onset signal bursts are delivered through loudspeakers in the sound field.

Interpreting the ASSR. Unlike the ABR, which is a transient response to a single transient stimulus repeated over time, the ASSR is a continuous “steady-state” neural response whose waveform follows the amplitude-modulated waveform of the ongoing stimulus. The operative assumption is that if the brain can detect the modulations of the stimulus, it has detected the stimulus itself. In this way stimuli that are most frequency specific, such as pure tones, may be used to obtain threshold estimates. Algorithms to automatically measure ASSR responses by computer eliminate some of the subjective nature of clinician interpretation of waveforms that is inherent in ABR testing.

Hall (2007) stresses that the ABR and ASSR are not competitive tests but rather complement each other when used in pediatric assessment. As Hall states, the ABR is the stronger measure in differentiation of the types of auditory dysfunction, while the ASSR is more valuable in estimating hearing for moderate to profound sensory/neural hearing loss. The ABR is accurate in establishing the presence of normal or mild-to-moderate hearing loss but not for losses of greater degree, while the ASSR may tend to overestimate hearing levels for those with normal hearing.

Auditory Middle Latency Response (AMLR) Audiometry

For some time it was uncertain whether the middle latency responses, which occur between 15 and 60 milliseconds after signal presentation, are myogenic (produced by changes in electrical potential generated in muscles on the scalp and behind the ear) or neurogenic (produced by electrical potentials in nerve units within the auditory pathways). It is now generally accepted that the AMLR has a neurogenic component. The AMLR reflects activity from the cortex and is therefore also called the early cortical auditory-evoked potential.

Patient setup for measurement of the AMLR is essentially the same as for ABR. A major difference lies in the importance of keeping the patient awake, as the amplitudes of the responses are reduced during sleep. As with the ABR and all other auditory-evoked potentials, it is important to keep the patient inactive to minimize myogenic artifacts. Patients must remain calm but alert. It may be necessary to average 500 to 1,000 responses to obtain a clear AMLR from clicks, filtered clicks, or tone bursts that may be delivered through an insert receiver or supraural earphone.

Interpreting the AMLR. The AMLR provides the same accuracy in frequency-specific threshold estimation as the ABR does. Indeed, the ABR and AMLR may be obtained simultaneously, giving the clinician more information about the auditory system in the same amount of time it takes to obtain one or the other response alone. The AMLR is also useful in the assessment of neurological function of the higher central auditory nervous system. Further refinement of

16. Like the ABR, the ASSR is (affected or not affected) by the patient's state of consciousness.

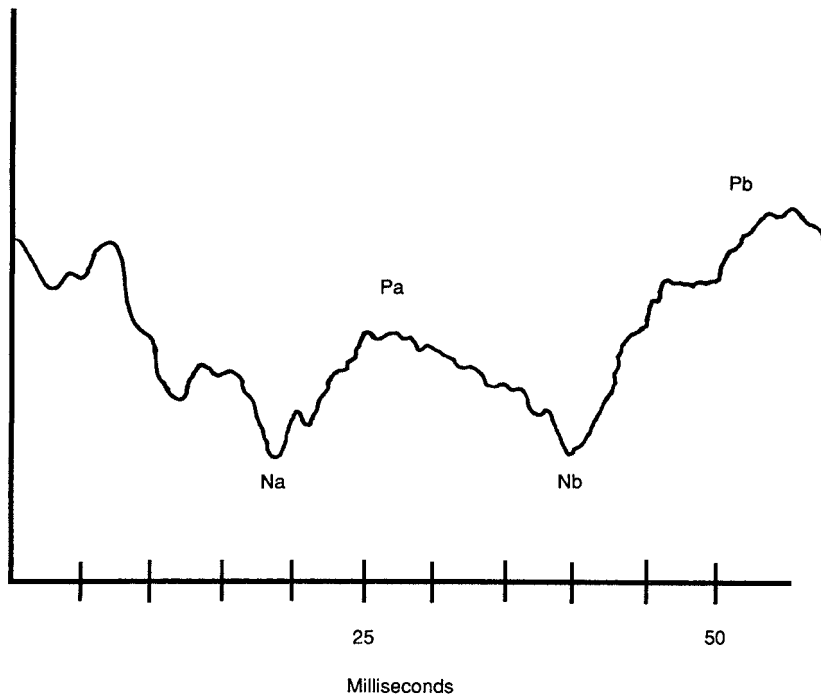


FIGURE 7.15 Auditory-evoked potentials showing the middle latency response providing information about hearing in the 2000 to 4000 Hz range.

AMLR measurement techniques will probably increase its use as a neurodiagnostic procedure. An AMLR response is shown in Figure 7.15.

Auditory Late Responses (ALRs)

The earliest work done on AEPs was on the late cortical auditory-evoked potential (CAEP), which includes those responses that appear at least 60 milliseconds after signal presentation (Figure 7.16). Problems in interpreting ALR test results, along with improvements in microcomputers and averaging systems, led to a much greater interest in the earlier components of the evoked response (ABR and AMLR), but in subsequent years renewed interest has been found in the later components. A major advantage of measuring the later responses is that it is possible to use frequency-specific stimuli, such as pure tones, as well as short segments of speech. The responses are considerably larger than the earlier waves and therefore can be tracked closer to the individual's behavioral threshold; however, unlike the ABR and ASSR the responses are affected by a patient's attention, and therefore the ALR has limitations when used with children. These potentials are dependent on state of consciousness; that is, significant degradation occurs with sleep, whether natural or induced. Because it is possible to use frequency-specific stimuli, such as pure tones, the ALR can therefore be used for threshold estimation as well as speech-assessment procedures.

The first late response (P1) often occurs at a latency of approximately 60 milliseconds after stimulus onset for a moderately intense tonal or speech sound. P1 is followed by a series of negative (N) and positive (P) waves (N1, P2, N2) occurring between 100 and 250 milliseconds. At approximately 300 milliseconds a larger (10 to 20 μ V) positive wave is seen. This response has become known as P300 or the auditory event-related response. The amplitude of the P300 can be made to increase significantly by having the patient count the stimuli (one per second).

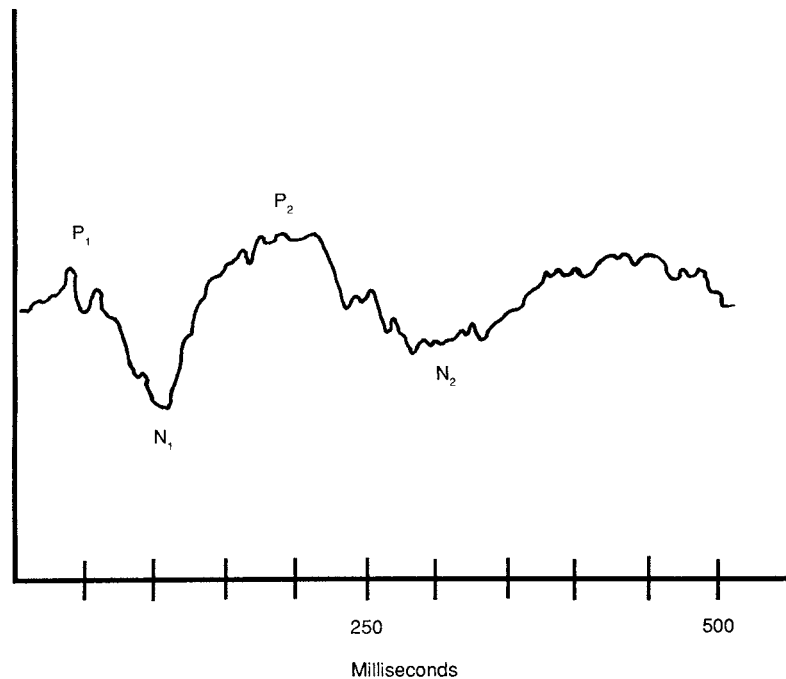


FIGURE 7.16 Auditory-evoked potentials showing the late evoked response. These responses are dependent upon a state of consciousness and exhibit significant degradation when patients are sleeping.

Another late evoked response, the **mismatch negativity (MMN)** has produced significant interest. This is a small negative electrophysiologic response using an oddball paradigm, for example, having “rare” stimuli at 2000 Hz presented 15% of the time along with “standard” stimuli like 1000 Hz presented 85% of the time (Kibbe-Michal, Verkest, Gollegly, & Musiek, 1986). However, unlike with the P300, the subjects are instructed to ignore both the rare and standard stimuli, which may both be present in the same ear or presented individually to different ears. The greater negativity on the waveform in response to the “odd,” or infrequently presented, stimuli compared to the response obtained to the standard, or frequent, stimuli reflects the neural response to a change in some physical attribute of the stimulus (e.g., pitch as in a 2000 Hz tone versus in a 1000 Hz standard tone). The effect is that different responses are evoked by the rare and standard signals, resulting in the acquisition of two different waveforms that are combined to obtain a different waveform containing the MMN. It is believed that the different responses to the rare and standard stimuli are due to the brain noticing a difference between the two stimuli, hence the term “mismatch” (Picton, 1995). The amplitude and latency of the MMN are related to the difference between the rare and standard signal rather than the absolute levels of these signals. The MMN is elicited in response to any change in auditory stimulation—frequency, intensity, rise time, duration, etc.—although very small changes may not be recognized within the normal background electrical noise of brain activity. The MMN, whose multiple generator sites include the temporal cortex, holds great promise for the understanding of how the brain conducts its cognitive functions (Näätänen, 1995). In addition, it may prove useful in differentiating disorders of auditory perception from disorders involving higher levels of function such as language, attention, and memory or in demonstrating the effects of speech-sound-discrimination training.

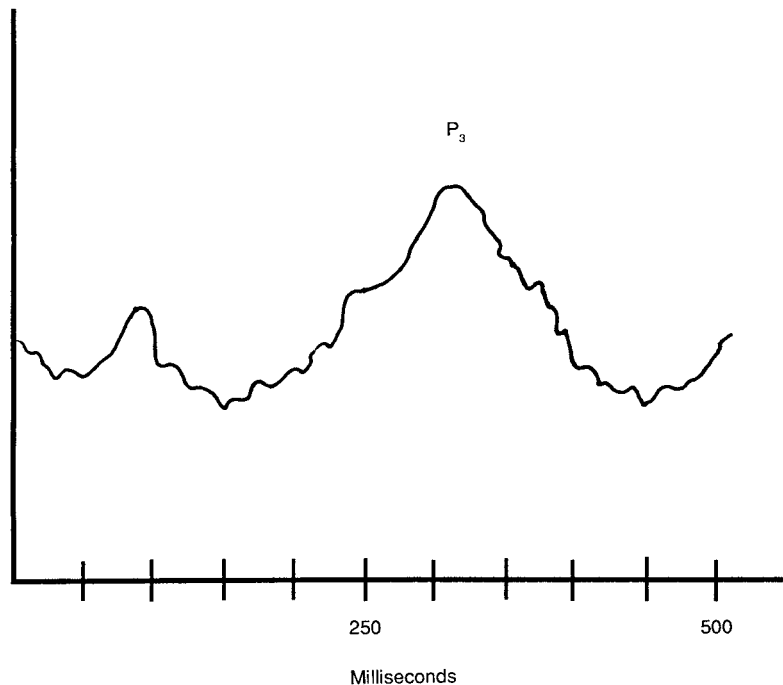


FIGURE 7.17 Auditory-evoked potentials showing the P300 (event-related) response, a response thought to be related to the processing of acoustic stimuli rather than the mere activation of the auditory nervous system.

Interpreting the Auditory Late Responses. Auditory late-evoked responses may aid in the estimation of threshold for pure tones over a wide frequency range and in the assessment of neurological function. Of course, if patients are awake and cooperative enough to allow late evoked responses, they can often be tested voluntarily. The P300 potential is called *event related* because it depends on discrimination of target stimuli by the listener (Figure 7.17).

For this reason the P300 is thought to be related to the perception or processing of stimuli rather than to the mere activation of the auditory nervous system by a stimulus. Late-evoked, P300, and MMN responses offer great promise for practical applications in diagnosis of neurological disease and injury. In addition, measured changes in the P1, N1, and N2 responses and the MMN response may find utility in the documentation of the effects of training to maximize the use of residual hearing (Tremblay & Kraus, 2002; Tremblay, Kraus, Carrell, & McGee, 1997).

17. The P300 is an AEP thought to be related to the _____ of the stimuli.

Intraoperative Monitoring

Improvements in equipment and procedures have also brought ABR testing into the operating room, where it is used to monitor responses from the brain during delicate neurosurgical procedures (Møller, 2000). Many of the electrical responses described above have been used for **intraoperative monitoring** of the physiological state of the patient. During these delicate operations surgeons often require reports on the condition of the patient, so that they may be alerted to possible damage to the auditory system before it occurs, thus averting both hearing loss and damage to other structures in the brain. Some operations that can benefit from this kind of monitoring include surgery on the auditory and facial nerves, as well as on the inner ear.

The modern operating room is filled with many people in addition to the surgeon and patient (anesthesiologists, technicians, and nurses) as well as a lot of electrical equipment that can generate signals that can interfere with monitoring of neuroelectrical responses. The operating room is not an easy work environment, and the persons performing these duties, who are increasingly audiologists, require very special training and skills. Intraoperative monitoring usually involves ECoG and ABR and is becoming part of the professional role of many audiologists.

A Historical Note

Separating conductive from sensory/neural hearing losses is not difficult on the basis of the pure-tone and speech tests described in Chapters 4 and 5, but the distinction between sensory (cochlear) and neural (lesions beyond the inner ear, or retrocochlear) is more difficult to determine. Prior to the advent of today's electroacoustical and electrophysiological tests, behavioral measures to separate sensory from neural hearing losses were extremely popular among audiologists. As more objective measures became increasingly available, research has shown that the sensitivity and specificity of the behavioral site-of-lesion tests are not always high. It can be argued that the use of multiple weak tests do not necessarily combine to create a strong differential battery (Durrant & Collet, 2002). Despite the general absence of these behavioral measures in today's testing protocols, they do illustrate some important concepts in normal audition and diagnostic audiology and as such, a brief historical review of select behavioral measures is presented here.

Loudness Balancing

Loudness increases with intensity in a logical and lawful manner. That is, as the intensity of a sound is increased, so is the experience of loudness. An appreciation and understanding of the growth in loudness perception in impaired ears has important clinical utility in fitting hearing aids.

We expect that normal ears will show a logical progression of loudness as intensity is increased. This is also true of patients with conductive hearing loss, so that 50 dB above the threshold of a person with a 10 dB threshold (50 dB SL, 60 dB HL) is as loud as 50 dB above the threshold of a patient with a 40 dB hearing loss (50 dB SL, 90 dB HL). In patients with lesions in the cochlea the loudness growth may be very rapid. Therefore, a patient with a threshold of 40 dB may experience a tone at 60 dB HL (20 dB SL) as being the same loudness that a person with a 0 dB threshold does at 60 dB HL (60 dB SL). This is called loudness **recruitment**. One can see that while the presence of recruitment is helpful in the diagnosis of a lesion site it can present serious problems for some people in wearing their hearing aids.

Patients with retrocochlear lesions either demonstrate no recruitment or may show **decreruitment**, which is a slower-than-normal increase in the loudness of a signal as intensity is increased. For example, a patient with a 40 dB hearing loss with decreruitment might experience a tone at 60 dB HL (20 dB SL) as being as loud as a tone at 90 dB HL (50 dB SL). This is called loudness decreruitment and is not always present with these lesions.

The best way to test for loudness recruitment in patients with unilateral hearing losses is by comparing the increase in loudness in the normal ear to the increase in loudness of the abnormal ear. This procedure is called the **alternate binaural loudness balance (ABLB) test**. While modern clinical audiometers still include circuitry for the administration of the ABLB, it is rarely performed by audiologists today (Martin, Champlin, & Chambers, 1998).

18. Loudness
recruitment is suggestive
of a lesion in the _____.

Clinical Commentary

As was mentioned earlier, acoustic reflexes are often observed at low sensation levels in patients who have lesions of the cochlea. This has been interpreted by some audiologists as a manifestation of loudness recruitment, which occurs because a tone presented at, say, 45 dB SL appears to be very loud (as loud as a 95 dB HL tone for those with normal hearing). There is no evidence that recruitment *per se* produces an acoustic reflex at low sensation levels, although both phenomena are often found in the same patients.

The Short Increment Sensitivity Index

For some time it has been known that patients with lesions in the cochlea are able to detect extremely small changes in intensity. Jerger, Shedd, and Harford (1959) developed a test based on this principle called the **short increment sensitivity index (SISI)**. The SISI is designed to test the ability of a patient to detect the presence of a 1 dB increment superimposed on a continuous tone presented at 20 dB SL. Twenty such increments are introduced, and patients with cochlear lesions are usually able to detect most of them, actually achieving scores at or close to 100%. Patients with retrocochlear and conductive loss, as well as those with normal hearing, do not have this ability and usually achieve scores close to 0%. Like the ABLB, modern clinical audiometers are still manufactured with circuit capability for administering the SISI test, although it is rarely performed today (Martin et al., 1998).

Tone Decay

In most cases, even among people with normal auditory systems, listening to sustained signals will bring about a certain amount of shift in an individual's thresholds for those signals; that is, the tone appears to die away. For many years it has been noted that patients with some forms of hearing disorder find it impossible to hear sustained tones for more than a brief time. To many of these patients, a tone heard clearly at a level 5 dB above threshold fades rapidly to inaudibility. If the level of the tone is increased, the tone may be heard again, only to disappear quickly to silence. This is called **tone decay**.

People with normal hearing and those with conductive hearing losses show virtually no tone decay. Those with cochlear lesions show some tone decay, perhaps up to 20 dB or so, but mostly in the higher frequencies (1000 Hz and above). Patients with lesions on the auditory nerve often show dramatic tone decay at all frequencies, which may be a powerful diagnostic sign.

19. Patients with rapid tone decay often have lesions in/on the _____.

Clinical Commentary

Compared to loudness balancing or the short increment sensitivity index, tone-decay testing has retained some clinical utility given its relatively high sensitivity, the limited clinical time required to administer it, and the absence of a need for any special equipment.

Békésy Audiometry

The use of a modern version of Békésy's automatic audiometer was once a popular audiological procedure that allowed patients to track their own auditory thresholds. During **Békésy audiometry** the patient presses a button when a tone becomes audible in an earphone, keeps the button depressed as long as the tone is heard, and then releases it when the tone becomes inaudible. The tone is allowed to increase in intensity until the button is pressed again, which causes the tone to be attenuated. A pen, controlled by the attenuator of the audiometer, traces the level of the tone on an audiogram as a function of both time and either fixed or constantly changing frequency.

The initial report of Jerger (1960) led to the use of Békésy audiometry as a clinical tool in the differential diagnosis of **site of lesion**. Observations were made of responses to continuous and to pulsed tones. The result of these observations was a series of five different types of Békésy audiograms. Because of the significant clinical time investment to complete Békésy testing, coupled with the procedure's low test sensitivity, Békésy testing is rarely used in clinical practice today.



EVOLVING CASE STUDIES

You will be asked to predict the results of the special tests described in this chapter on the four case studies that have been developed. These tests will include acoustic immittance, acoustic reflex thresholds (ART), otoacoustic emissions (OAE), and auditory brain-stem responses (ABR). The first two tests just named are performed routinely on patients who appear for audiometric evaluation. While OAEs are obtained routinely in some clinics, like ABR testing they are usually reserved for special occasions when additional diagnostic information is required. For this exercise, please predict the possible/probable results on all four types of tests. Because of the individual natures of the disorders in these case studies, you will be referred for discussion of these tests to other chapters where the pathologies are covered in greater detail.

Case Study 1: Conductive Hearing Loss

Continues at the end of Chapter 10.

Case Study 2: Sensory/neural Hearing Loss

Continues at the end of Chapter 11.

Case Study 3: Erroneous Hearing Loss

Continues at the end of Chapter 13.

Case Study 4: Pediatric Patient

Continues at the end of Chapter 8.

Summary

Acoustic immittance measurements give remarkably reliable information regarding the function of the middle ear. Both static compliance and tympanometry are measures of the mobility of the middle-ear mechanism. Distinctive tympanometric patterns combined with other audiometric

findings can aid the clinician in determining the underlying pathology of a conductive hearing loss. The acoustic reflex and reflex decay give information regarding probable disorders of different areas of the auditory system. There is no doubt that the acoustic immittance meter has become as indispensable to the audiologist as the audiometer.

The introduction of otoacoustic emissions to the test battery is a giant leap in the direction of testing patients who cannot or will not cooperate during voluntary hearing tests. The advantages to using OAEs with children are obvious. This procedure is noninvasive and requires no patient cooperation, except to remain relatively motionless. Data-collection time has been estimated at 1 to 5 minutes per ear, which is very advantageous considering that children tend to be active. Otoacoustic emissions have added significantly to the battery of tests for site of lesion. OAEs may be used in combination with evoked potential measures to help differentiate sensory from neural lesions and may also be utilized as a cross check of middle-ear status, as determined by acoustic immittance measures.

Auditory brain-stem response (ABR) audiometry has become an important part of the site-of-lesion test battery, and some of the other evoked potential techniques are becoming more valuable as they are improved. Using computer averaging techniques and a series of acoustic stimuli, it is possible to evoke responses on the basis of neuroelectric activity within the auditory system. By looking at the kinds of responses obtained during electrocochleography and auditory brain-stem response audiometry, along with the later components of electroencephalic audiometry, it is often possible to predict the site of lesion and estimate auditory threshold. Many of these tests are finding their way into the operating room for monitoring during neurosurgery. Although the ABR should be considered to be more a test of synchronous neural firings than of hearing *per se*, its value to diagnostic audiology and to neurological screening is well established.

Tests like the alternate binaural loudness balance test, SISI, tone decay, and Békésy audiometry have largely been replaced by the more objective procedures. Students interested in a more detailed presentation of behavioral site-of-lesion testing may consult Brunt (2002).

REVIEW TABLE 7.1 Summary of Objective Tests

<i>Test</i>	<i>Purpose</i>	<i>Measurement Unit</i>
Tympanometry	Pressure-compliance function of TM	cm ³
Static Compliance	Compliance of TM	cm ³
ART	Sensation level of acoustic reflex	dB
ABR	Latency-intensity function of early AEP	msec
OAE	Check cochlear function	dB

REVIEW TABLE 7.2 Typical Interpretations of Objective Tests

	<i>Normal Hearing</i>	<i>Conductive Loss</i>	<i>Sensory Loss</i>	<i>Neural Loss</i>
Tympanogram Type	A	A _D , A _S , B, or C	A	A
Static Compliance (cm ³)	0.3 to 1.6	<0.3 or >1.6	0.3 to 1.6	0.3 to 1.6
ART	Present at 85 to 100 dB SL	Absent or >100 dB SL	Present at <65 dB SL	Absent or >100 dB SL
ABR	Normal Wave V and interpeak latencies	All wave latencies prolonged	Slightly increased Wave V and interpeak latencies	Very increased Wave V and interpeak latencies
OAE	Present	Absent	Absent	Present

Related Websites

Tympanometry

www.utmb.edu/pedi_ed/aom-otitis/tympanometry/tympanometry.htm

Otoacoustic Emissions

<http://emedicine.medscape.com/article/835943-overview>

Auditory Brain-stem Response

<http://emedicine.medscape.com/article/836277-overview>

Study Questions

1. Describe the equipment needed for each of the tests described in this chapter.
2. Why is the term “impedance audiometry” inaccurate?
3. What are the three basic measures made during acoustic immittance testing?
4. What are the relationships of OAE and ABR thresholds to voluntary thresholds?
5. What are the theoretical and practical values of the measures described in this chapter?
6. Describe the limitations of the tests described in this chapter.
7. With the knowledge of the audiological tests you have gained in your reading, with what test would you start in a routine hearing evaluation and why?
8. The first measure made in determination of static acoustic compliance (the c_1 reading) is indicative of what important clinical observation?
9. What can acoustic reflex thresholds (ARTs) and/or otoacoustic emissions (OAEs) reveal about the hearing of a difficult-to-test patient? What would the limitations of these measures be?

Suggested Readings

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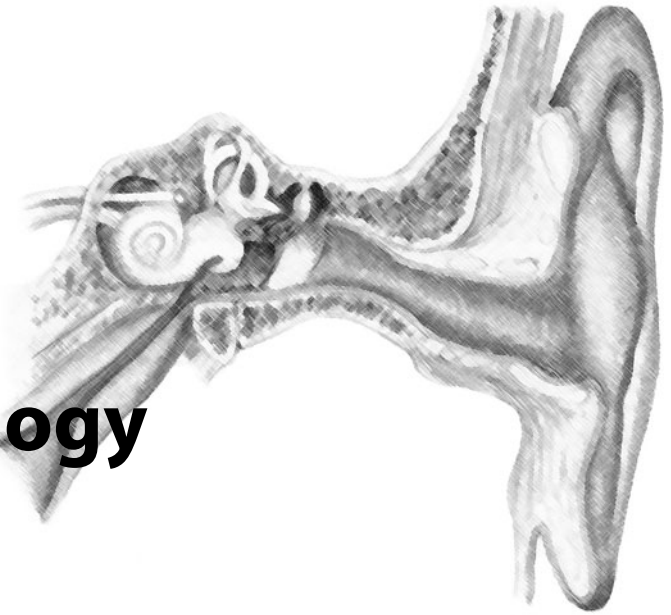
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CHAPTER 8

Pediatric Audiology



FOR A VERY LONG TIME children with hearing loss were denied the most basic of human rights. Those who reached adulthood could be denied the rights to marry, conduct business in their own names, and even to own property. Hearing loss was considered a major justification for infanticide, decisions about which were legally determined by the fathers, a policy that was not officially opposed until about 400 C.E. Unquestionably, the human race, for the most part, has come a very long way, although the means and motivation for pediatric audiology are not universally extant.

Most of the audiometric procedures described earlier in this text can be applied with great reliability to children beyond ages 4 or 5 years. In such cases, the examination is often no more difficult than it is with cooperative adults. However, in many instances, because of the level at which a particular child functions, special diagnostic procedures must be adopted. Since the prevalence of hearing loss in children has been estimated to range from between 1 and 2.5 per 1000 (Davidson, Hyde, & Alberti, 1989; Mauk & Behrens, 1993) up to 6 per 1000 (Hayes & Northern, 1996), the need for pediatric audiology is self-evident.

LEARNING OBJECTIVES

This chapter presents information on early hearing-loss identification and a variety of techniques that have proved helpful in obtaining information about the auditory function of children who cannot be tested using usual audiometric procedures. Methods are described to determine the presence, type, and extent of hearing loss in children. Upon completion of this chapter, the reader should be able to

- Describe the various responses that infants may give to auditory signals and how levels of sleep may affect these responses.

- List the components and goals of an early hearing detection and intervention program.
- Describe various test approaches with young children, providing discussion of what measures may be appropriate at different age levels and how the child may respond.
- Describe the components of a successful school hearing screening program and the equipment and screening measures that would be employed for hearing screening in the schools.
- Discuss how special diagnostic difficulties may be presented by complications such as auditory processing disorders and erroneous hearing loss.

Auditory Responses

It has been stated in this book that what is measured with hearing tests is not hearing itself, but rather a patient's ability and/or willingness to respond to a set of acoustic signals. Therefore, whatever determination is made about the hearing of any individual is made by inference from some set of responses. The hearing function itself is not observed directly.

The manner of a patient's response to some of the tests described earlier has not been considered to be of great concern. For example, it is not important whether the patient signals the awareness of a tone by a hand signal, by a vocal response, or by pressing a button. With small children, however, the manner and type of response to a signal may be crucial to diagnosis. It is also important to remember that most small children do not respond to acoustic signals at threshold; rather, sounds must be more clearly audible to them than to their older counterparts. It is safe, therefore, to assume that during audiometry small children's responses must be considered to be at their **minimum response levels (MRLs)**, which in some cases may be well above their thresholds (Table 8.1).

Responses from small children may vary from voluntary acknowledgment of a signal to involuntary movement of the body, or from an overt cry of surprise to a slight change in vocalization. Response to sound may be totally unobservable, except for some change in the electrophysiological system of the child being tested. If a clear response to a sound is observed by a trained clinician, it may be inferred that the sound has been heard, although the sensation level

1. Since many children do not respond at threshold during auditory tests, their responses are often called _____.

TABLE 8.1 Typical Sound-Field Minimum Response Levels for Normal-Hearing Children Birth to 24 Months of Age (Martin & Clark, 1996)

<i>Age (Months)</i>	<i>Noisemakers (dB HL)</i>	<i>Warble Tones (dB HL)</i>	<i>Speech (dB HL)</i>
0 – 4	40	70	45
4 – 6	45	50	25
6 – 8	25	45	20
8 – 10	20	35	10
10 – 14	20	30	10
14 – 20	20	25	10
20 – 24	15	25	10

of the signal may be very much in question. Conversely, if no response is observed, it cannot be assumed that the sound has not been heard.

Obviously, a number of factors contribute to the responses offered by a child. Of primary concern is the physiological and psychological state prior to stimulation. Shepherd (1978) describes pre-stimulus activity levels as a range consisting of alert attentiveness, relaxed wakefulness, drowsiness, light sleep, and deep sleep. Students of audiology should spend time observing normal children to understand motor development, language and speech acquisition, and auditory behaviors.

Even though audiologists may have preferences for certain kinds of responses from a child, they must be willing to settle for whatever the child provides. Audiologists must also be willing to alter, in midstream, the kind of procedure used if it seems that a different system might be more effective. Modification of a procedure may be the only way to evoke responses from a child, and flexibility and alertness are essential. Response to a sound may appear only once, and it may easily be lost to the inexperienced or unobservant clinician.

Identifying Hearing Loss in Infants under 3 Months of Age

Speech and language are imitative processes, acquired primarily through the auditory sense. A hearing defect, either congenital or acquired early in life, can interfere with the development of concepts that culminate in normal communication. Of the 4 million babies born annually in the United States, it can be expected that about 1 to 3 per thousand will have some degree of hearing loss. In the absence of hearing screening at birth, many children with abnormal hearing proceed into the third year of life or beyond before a hearing problem is suspected. A hearing disorder in a child is often not detected because parents believe that, if their own child had a hearing loss, they would somehow know it because he or she would be obviously different from other children.

There has also been a mistaken notion that babies with hearing loss do not babble. It is probable that the act of babbling is a kind of vegetative activity that is reinforced by a child's tactile and proprioceptive gratification from the use of the mouth and tongue. Around the age of 6 months, children with normal hearing begin to notice that those interesting cooing sounds have been coming from their own mouths, and they begin to amuse themselves by varying rate, pitch, and loudness. Often, children with impaired hearing, who do not receive adequate auditory feedback, will gradually decrease their vocalizations. In contrast, children with normal hearing will begin to repeat, in parrot-like fashion, the sounds they hear. Eventually, meaning becomes attached to sounds, and the projective use of words is initiated. Usually, the normal-hearing child is speaking well before the age of 2 years; the child with an auditory deficit is not.

The average age at which children with hearing losses were identified in the United States in the early 1990s was nearly 3 years of age (National Institutes of Health, 1993), whereas in Israel it has been between 7 and 9 months (Gustafson, 1989). This significant difference can be attributed primarily to the differences in the healthcare delivery systems in the two countries and the auditory screening procedures used. With the knowledge that profound hearing loss in children is declining, whereas mild losses are on the increase, and that these mild losses produce more difficulties for children than had been supposed (Tharpe & Bess, 1991), it is generally agreed that early identification of hearing loss is of paramount importance. The earlier in the life of a child that specific educational and training procedures can be initiated, the greater the chance that they will be successful. There is, of course, no earlier time that testing can begin than immediately after birth. It is for these reasons that legislation for the implementation of universal infant hearing screening has been passed throughout most of the United States. Since the implementation of newborn hearing screening programs an encouraging trend has been seen in the reduction of the age of hearing loss identification and subsequent intervention (Harrison, Roush, & Wallace,

2003). The purpose of Early Hearing Detection and Intervention (EHDI) programs is to identify children with hearing loss before they reach the age of 3 months.

A number of criteria must be met before newborn screening of any disorder can be justified. These include (1) a sufficient prevalence of the disorder to justify the screening, (2) evidence that the disorder will be detected earlier than would be the case without screening, (3) the availability of follow-up diagnostics immediately after the failure of a screening, (4) treatment accessibility immediately following diagnosis, and (5) a documented advantage to early identification. All of these criteria are easily met in the argument for newborn hearing screening.

Infant Hearing Screening

Hearing screening procedures can be justified on several bases, including cost efficiency. When compared with other disorders for which screening is routine, such as phenylketonuria (PKU) or neonatal hypothyroidism, the yield is considerably higher for hearing loss. As a matter of fact, hearing loss of varying degrees has been ranked sixth in prevalence of chronic conditions in the United States (U.S. Department of Health and Human Resources, 1993). Simmons, McFarland, and Jones (1980) found hearing loss in 1 out of 50 infants who graduated from an intensive care nursery. Within the general population, reported prevalence data vary because of differences among studies in screening procedures and definition of hearing impairment, but prevalence may be as high as six babies with significant hearing loss in every 1,000 births (Hayes & Northern, 1996). From a purely objective and financial viewpoint, the fact that hundreds of millions of dollars might be saved each year if early identification and habilitation of hearing impairments were in place, seems to justify neonatal hearing screening, even if the obvious humanitarian aspects are ignored.

Apgar¹ (1953) developed a system for evaluating newborns that is used in many hospitals today. The procedure now utilizes an acronym based on her name: A (appearance), P (pulse), G (grimace), A (activity), R (respiration). Basically the **Apgar Test** score evaluates the normalcy of respiratory effort, muscle tone, heart rate, color, and reflex irritability. The evaluation of the newborn is usually carried out by trained nurses who assign values of 0 to 10 at 1, 5, and 10 minutes after birth. These evaluations help to determine whether the child requires additional oxygen and whether there is a likelihood of central nervous system damage. Children with low Apgar scores should also be suspected of having sensory/neural hearing loss. Inexperienced audiologists enter their professional careers with little time spent in observing the behaviors of normal infants. Their initial professional experiences are often with children who have problems, which they must diagnose without a satisfactory standard for comparison. Learning the sometimes-subtle differences in the appearance and behaviors between children with and without normal hearing is one of the vast benefits of clinical experience since diagnostic decisions are often based on subjective impressions.

Walker (2003) discussed the importance of early diagnosis of hearing loss as part of a “diagnostic imperative.” There appears to be a biological relationship between newborn hearing loss and other conditions including Sudden Infant Death Syndrome (SIDS). Both may be due to congenital deficiencies of important enzymes like biotin, which can lead to a wide variety of disorders of the auditory and other systems, including the heart, eye, and musculoskeletal system, as well as the predisposition to infection. Early detection of hearing loss may help lead to prevention or treatment of these other disorders. Walker considers “maladaptive parenting,” along with these deficiencies, to be a major medical consideration for children. These findings add to the urgency of neonatal screening.

2. Apgar is a procedure for evaluating _____.

The History of Neonatal Hearing Screening. Wedenberg (1956) screened 150 infants between the ages of 1 and 7 days by hitting a cowbell with a hammer close to the child's head. Of the infants, 149 responded with an **auropalpebral reflex (APR)**, which is a contraction of the muscles surrounding the eyes. Wedenberg subsequently used an audiometer, which powered a small loudspeaker positioned near a sleeping child's head. Testing with a variety of frequencies, he observed responses (in the intensity range from 104 to 112 dB SPL) from normal-hearing infants in light sleep. He noted that premature children do not respond well to external stimuli, and that arousal responses depend, to a large extent, on the sleep level of the child.

3. The auropalpebral reflex is a _____ of the muscles around the _____.

Downs and Sterritt (1967), using a specially designed device to produce a 3000 Hz warble tone, found that they could observe responses of most infants at about 90 dB SPL. Responses consisted primarily of APRs, movement of the hands or head, or overall startle responses. These researchers tested about 10,000 infants using this procedure, with only 150 failing, 4 of whom were subsequently identified as having hearing losses.

For a time, these kinds of results suggested that screening the hearing of neonates before they leave the hospital might be the method by which early identification and follow-up could be achieved. There were, however, several problems. The training of the individual performing the test is of great importance. Attendance by a separate observer is often useful, but disagreements on acceptance of responses occur. Because a number of children with normal hearing may fail the screening, informing their parents of possible hearing loss may produce undue alarm and concern. Additionally, startle responses to high-intensity sounds may be observed from children with moderate hearing losses who show loudness recruitment. In large measure because of the lack of a sophisticated means to test the hearing of neonates, it looked for a time that the goal of large-scale screening, noble though it was, was just too impractical to implement.

A joint committee on infant hearing (JCIH) in 1994 outlined a **high-risk registry** containing a list of indicators of hearing loss for identifying newborns who should be screened for hearing loss. The JCIH later endorsed the goal of universal screening of all newborn children while maintaining a modification of the previously described high-risk registry for identifying children to be screened where universal screening of all newborns was not yet available (JCIH, 2000). Universal newborn hearing screening (UNHS) was recognized as the favored approach to the identification of hearing loss in newborns, as the high-risk registry lacks the specificity required to find the majority of children at risk for hearing loss. In fact, Mehl and Thomson (1998) state that selective hearing screening based on high-risk criteria fails to detect at least half of all infants with congenital hearing loss. An obvious difficulty in using the high-risk registry lies in the fact that many hereditary hearing losses are of a recessive nature, and the genetic potential for hearing loss may exist without an obvious family history of this disorder.

4. The main purposes of infant hearing screening are _____ and _____.

At this time the JCIH (currently comprised of the American Academy of Audiology, the American Speech-Language-Hearing Association, the American Academy of Otolaryngology-Head and Neck Surgery, the American Academy of Pediatrics, the Alexander Graham Bell Association for the Deaf and Hard of Hearing, the Council on Education of the Deaf, and the Directors of Speech and Hearing Programs in State Health and Welfare Agencies) has fully endorsed UNHS through an interdisciplinary system of early hearing detection and intervention (JCIH, 2007). Although the cost per child for UNHS is significantly higher than screening tests performed on blood, the higher incidence of congenital hearing loss results in a comparable cost per case diagnosed. In fact, the incidence of bilateral congenital hearing loss discovered is many times greater than the combined incidence of all newborn screening tests currently conducted on blood samples (Mehl & Thomson, 1998).

TABLE 8.2 Indications of Risk for Permanent Congenital, Delayed-Onset, or Progressive Childhood Hearing Loss

1. Concerns from parents or other caregivers of speech, language, hearing, or developmental delay.*
2. Family history of permanent childhood hearing loss.*
3. Neonatal intensive care greater than 5 days or any of the following regardless of length in the neonatal intensive care unit: ECMO virus,* assisted ventilation, ototoxic medications or loop diuretics or hyperbilirubinemia requiring exchange transfusion.
4. In utero infections including CMV,* herpes, rubella, syphilis, and toxoplasmosis.
5. Craniofacial anomalies including the pinna, ear canal, ear tags, ear pits, and temporal bone abnormalities.
6. Physical findings, such as white forelock, that are associated with a syndrome known to include sensory/neural or conductive hearing loss.
7. Syndromes associated with hearing loss or progressive or late-onset hearing loss* such as neurofibromatosis, osteopetrosis, and Usher syndrome; other frequently identified syndromes such as Waardenburg, Alport, Penrod, Jervell, and Lange-Nielson.
8. Neurodegenerative disorders,* such as Hunter syndrome, or sensorimotor neuropathies such as Friedreich's ataxia and Charcot-Marie-Tooth syndrome.
9. Culture-positive postnatal infections associated with sensory/neural hearing loss,* including confirmed bacterial and viral (especially herpes viruses and varicella) meningitis.
10. Head trauma, especially basal skull/temporal bone fracture* that require hospitalization.
11. Chemotherapy.*

* Indicators with higher concern for delayed-onset hearing loss

Source: JCIH (2007)

Although successes of implementing UNHS are numerous, many who fail the screening still do not receive appropriate follow-up to confirm the presence of hearing loss or to institute early intervention. A full accounting of risk indicators associated with permanent congenital, delayed onset, or progressive hearing loss in children as currently outlined by JCIH is listed in Table 8.2.

Since some hearing losses are **hereditodegenerative**, a child failing on the high-risk registry because of family history might pass an early screening, lulling the family into a false sense of security about the potential for later development of a hearing loss. Indeed, Mann, Cuttler, and Campbell (2001) report that one of the greatest weaknesses of any newborn hearing screening program is ensuring adherence to follow-up guidelines for those who pass the screen yet may be considered at high risk for hearing loss.

Neonatal Screening with ABR

Auditory brain-stem response (ABR) audiometry has become increasingly popular as a neonatal testing system (Figure 8.1). Some of the disadvantages of this procedure have been discussed previously in Chapter 6: for example, the lack of frequency specificity evident when click stimuli are used. When testing infants on the high-risk registry, it is important to compare responses to norms that correspond to children's gestational ages, rather than to their chronological ages, because immaturity of the central nervous system in a premature child can have a profound effect on results and must be taken into account. Follow-up testing is essential when ABR results are either positive or negative for infants on the high-risk registry.

Equipment used for measuring ABRs in infants was initially rather costly and more sophisticated than that which was required in the neonatal nursery. Less expensive, dedicated units that have a higher degree of portability without sacrifice in quality have replaced this equipment. In recent years automated systems have been developed that are easy to use, require little in the way of interpretation of results, and can be used by trained technicians, including



FIGURE 8.1 Auditory brainstem response measurement is one method for screening neonatal hearing. (Image courtesy of Natus Medical Incorporated)

volunteers. Electrodes and earphones are disposable and easy to apply and remove. Results with this kind of equipment have been very encouraging and can have a pronounced effect on lowering the cost of neonatal screening.

Neonatal Screening with Otoacoustic Emissions

The use of otoacoustic emissions (OAE) as a neonatal screening method has emerged rapidly in recent years (see Bonfils, Dumont, Marie, Francois, & Narcy, 1990; Bonfils, Vziel, & Pujol, 1988; Kemp & Ryan, 1993; Norton, 1994). Over 6,000 infants were investigated in the Rhode Island Hearing Assessment Project (RIHAP) (Maxon, White, Vohr, & Behrens, 1992). The OAEs have been shown to be specific, sensitive, and cost-effective measures in infants.

If all the requirements can be met, including a tightly fitting ear piece, quiet test environment, and so on, it can be assumed that infants whose ears produce evoked emissions have normal peripheral hearing, or no worse than a 30 dB hearing loss. The first few days of life are ideal for measuring OAEs, since bodily movement makes it difficult to perform and evaluate, and neonates spend many hours each day in sound sleep. However, the presence of even a slight conductive hearing loss eliminates the measurable emission. Those who fail the OAE screenings should be followed up with ABR or other testing as deemed appropriate by the attending clinician.

As discussed in Chapter 7, the origin of the otoacoustic emission is the outer hair cells of the cochlea. If the cochlea is normal and a lesion exists in a retrocochlear area, there is a good chance for normal-appearing emissions to be evoked. This fact produces a cogent argument in favor of a combination of OAE and ABR testing. Some screening programs pass an infant when an ABR screen is passed following a failed OAE screen. Given that a failed OAE may signify outer hair cell damage, some have questioned if such practice might be missing an early predictor of late-onset progressive hearing loss in children if strict adherence to follow-up guidelines is not maintained (Mann et al., 2001). In spite of these concerns, an OAE screen followed by an ABR screen on those who fail has been reported to be successful both in enhanced identification and program cost reductions (Gorga, Preissler, Simmons, Walker, & Hoover, 2001). Hall, Smith, and Popelka (2004) recommend the use of essentially concurrent screenings of both OAE and ABR as a more effective screening approach than the use of either measure alone.

Auditory neuropathy/dys-synchrony (AN/AD) is often missed in newborn children because most hospitals screen using otoacoustic emissions. OAE tests for responses to sound by the outer hair cells of the cochlea but does not reveal how the brain responds. Therefore, a typical newborn hearing screening program may not identify a child with AN/AD. There are some children who will have some abnormal cochlear function causing reduced OAE responses, in addition to AN/AD, that can be identified during newborn hearing screening.

Patients with auditory neuropathy/dys-synchrony exhibit no auditory brain-stem response (ABR), no middle-ear muscle response, and both normal otoacoustic emissions and normal cochlear microphonics. An absent or grossly abnormal ABR is not always associated with deafness. In contrast, a hearing loss of 30 dB or more usually predicts absent otoacoustic emissions, but normal emissions can be seen in some patients whose behavioral audiograms imply total deafness.

5. Major advantages of using OAEs for infant hearing screening is that they are _____ and _____.

Meeting the Needs and Challenges of Newborn Hearing Screening

Approximately four million infants are born in the United States each year, creating a tremendous strain on personnel who may be qualified to perform newborn hearing screenings. Clearly there exists a need for supportive technicians who can work under the direction and supervision of audiologists so that the challenges of screenings can be successfully met. The use of support personnel for newborn screenings frees valuable time for the audiologist whose efforts may more meaningfully be directed toward the provision of follow-up, diagnostic, and intervention services. Delineated duties of support personnel may include ensuring proper maintenance of screening equipment, operating screening devices in accordance with training received, disseminating information to appropriate personnel, cleaning/disposing of screening supplies, and completing records as required (AAA, 2004).

Beyond Early Identification

Any neonatal hearing-loss-identification program should be only a component part of a comprehensive program aimed at providing children with hearing loss the greatest chances possible for educational success and a subsequent entry into the mainstream of society. A comprehensive early hearing detection and intervention (EHDI) program will comprise three components: a birth admission hearing screening, follow-up and diagnostic evaluations for those infants who fail, and an intervention program with a goal of implementation before 6 months of age. Children identified

and placed within an intervention program prior to 6 months of age exhibit significantly higher developmental functioning compared to children identified after 6 months of age (Yoshinaga-Itano, Sedley, Coulter, & Mehler, 1998).

Objective Testing in Routine Pediatric Hearing Evaluation

Children may be referred to the audiologist for evaluation following neonatal hearing screening or subsequently due to parental or pediatrician concerns of auditory responsiveness or delayed speech and language development. Experienced audiologists do not launch quickly into hearing tests with small children. Even before beginning objective tests, they spend some time casually observing each child (Tables 8.3 and 8.4). They should notice such factors as the children's relationships with the adults who have taken them to the clinic; their gaits, standing positions, and other indications of general motor performance; and their methods of communication. Compiling complete and detailed case histories is of paramount importance since they constitute a significant portion of the diagnosis. Special attention should be paid to noteworthy events during the prenatal, perinatal, and postnatal periods, family history, and any other such details. When dealing with families whose native language is not spoken English, the use of a translator is often essential.

ASHA's most recent guidelines for pediatric hearing assessment (ASHA, 2004) recommend that testing include behavioral, physiologic, and developmental measures with a corroboration of test results with the child's case history, parental reports, and the clinician's behavioral

TABLE 8.3 Childhood Communication Development Checklist*

Modified from "Your Child's Speech and Hearing" developed by the Psi Iota XI sorority and the American Speech-Language-Hearing Foundation.

<i>Age</i>	<i>Behavior</i>
Birth – 3 months	Child may startle or cry to loud noises; awaken to loud sounds; listen to speech; smile when spoken to. Child will begin to repeat the same sounds (cooing).
4 – 6 months	Responds to "no" and changes in parental tone of voice; looks for the source of household sounds; notices toys that make sounds. Babbling begins to sound more speech-like with a variety of sounds including bilabial consonants. Child may communicate by sound or gesture when he or she wants parent to do something again.
7 months – 1 yr.	Recognizes common words like "cup," "shoe," or "juice." Responds to requests such as "Come here," "Want more?" Turns when name is called and listens when spoken to. Enjoys simple games like pat-a-cake and peek-a-boo. Imitates different speech sounds. May have one or two words (although possibly not clear), i.e., mamma, dada, bye-bye, no.
1 – 2 yrs.	Will point to pictures in a book, or body parts, when named. Follows simple commands and understands simple questions (Roll the ball. Where's your shoe?). Vocabulary is expanding each month. Begins to use one- or two-word sentences (Where kitty? What that? No cookie. More juice.).
2 – 3 yrs.	Understands differences in meaning (big-little, stop-go, up-down). Can follow two requests ("Get the ball and put it on the table."). Uses two- to three-word sentences and has a word for almost everything. Parents can understand the child's speech most of the time.
3 – 4 yrs.	Will answer simple "who," "what," "where," and "why" questions. Talks about what he or she does at school or a friend's house. Says most sounds correctly except for later developing sounds like r, l, th, and s. People outside the family usually understand child's speech. Should be using a lot of sentences with four or more words.

*Note: A wide range of normal developmental variability exists among children. Substantial deviation from expected norms may indicate a developmental lag.

TABLE 8.4 Childhood Motor Developmental Checklist*

Modified from the “Rapid Developmental Screening Checklist” developed by the Committee on Children with Handicaps, American Academy of Pediatrics, New York Chapter 3, District II.

<i>Age</i>	<i>Behavior</i>
Birth – 3 months	Child can raise head from a supine position. Will look at face when directly in front of him or her. Eyes will follow a moving object.
4 – 6 months	Can hold onto a rattle. Reaches for and grasps objects. Can turn over. Turns in response to sound. Sits with minimal support.
7 months – 1 yr.	Can move an object from hand to hand. Can sit alone momentarily. Can sit for several minutes without support. Can pull himself up by holding onto things. Can move around the crib, or walk holding onto supports.
1 – 2 yrs.	Will wave good-bye or in response to others. Can walk with only one hand held. Can walk alone. Can balance three blocks together.
2 – 3 yrs.	Can run. Can go up and down stairs. Can jump with both feet. Can stack six or more blocks together.
3 – 4 yrs.	Can build a nine-block tower. Can copy a circle.

* Significant deviation from the normative values above may warrant further evaluation. Prior to 2 years of age, the checklist should be adjusted for premature birth by subtracting the number of weeks of prematurity from the child's age.

observations. The first measures in the pediatric hearing evaluation are often the objective measures of otoacoustic emissions and immittance testing, both of which are discussed more fully in Chapter 7. If present, otoacoustic emissions can quickly give the audiologist the knowledge that hearing is no worse than the level of a mild hearing loss. Tympanometry can determine a number of middle-ear disorders, including abnormal middle-ear pressure, eustachian tube dysfunction, effusion, mobility, and integrity of the middle-ear ossicles, thin or perforated tympanic membrane, and patency of pressure-equalization tubes. Additionally, the sensation level or absence of the acoustic reflex can give general kinds of information about a possible sensory/neural hearing loss. Subsequent pure-tone testing (preferably done with insert earphones to circumvent potential ear canal collapse from the pressure of supra-aural earphones) can yield meaningful results without the addition of bone-conduction measures if normal tympanograms and the presence of acoustic reflexes have ruled out a conductive component to any identified hearing loss.

A major problem with otoacoustic emissions and immittance tests with very small children results when children move about or cry. For a test to be accurate, the patient must be relatively

6. If otoacoustic emissions are present, hearing loss is no greater than _____.

motionless. Furthermore, any vocalizations—for example, crying—will be picked up by the probe microphone. An experienced team of clinicians can often work so efficiently that children are distracted and tested before they have time to object. At what point in the evaluation these measures are conducted with young children is often a judgment call. Infants and very young children will usually accept administration of these measures with minimal objection while held in their parent's arms. The benefits of completing these tests at the outset of the evaluation may be outweighed by the advantage gained by building some degree of rapport with older children through the completion of other tests that may seem less frightening to some children. Sometimes a good time for these objective measures with small children is between speech and pure-tone testing.

Clinical Commentary

Regardless of the age of a child, it is frequently prudent to begin testing with the measurement of otoacoustic emissions (OAE). If emissions are normal, conductive hearing loss can be ruled out, and any possible sensory/neural hearing loss can be assumed to be no worse than a mild deficit. If emissions are absent, further testing is needed to illuminate both the type and degree of loss. OAEs do not depend on maturation of the auditory system and so can be performed as early in a child's life as is practicable. Since Distortion Product Otoacoustic Emissions (DPOAEs) provide information in the frequency range between 500 and 4000 Hz, they can be especially useful in diagnoses when they can be obtained.

Immittance measures as the next test will reveal further information on a suspected conductive hearing loss when OAEs are absent. If OAEs were normal, suggesting normal middle-ear functioning, then tympanometry will be normal and comparison of acoustic reflex thresholds for pure tones and broadband noise can help predict the degree of any existing loss. This knowledge can be helpful as the audiologist moves into behavioral assessment with the child. Often the usual probe-tone frequency of 220 Hz fails to elicit acoustic reflexes in infants and a higher frequency of 660 Hz offers a higher yield of positive responses. Of course, if tympanometry is abnormal, precluding acoustic reflex measures, little can be said of hearing sensitivity, and without further testing the examiner cannot rule out the possibility of a conductive hearing loss overlaying any potential sensory/neural hearing loss the child may have.

Behavioral Testing of Children from Birth to Approximately 2 Years of Age

It is unusual for a child to be seen for evaluation before 1 year of age unless the possibility of hearing impairment has been suggested through some means of newborn or infant hearing screening. At 1 year of age, the child with hearing loss may begin to lose the potential for normal spoken-language development. For this very reason early screenings are of great importance. Lack of speech often brings a potential problem to the attention of the parents or other caretakers.

At 18 months, the normal child usually obeys simple commands. Speech tests are useful to evaluate children at this age, as a child may give good responses to soft speech while apparently ignoring loud sounds. It is interesting that quiet-voiced speech will sometimes elicit a response when whispered speech will not.

It has been frequently observed that in general the broader the frequency spectrum of a sound, the better it is at catching the attention of a small child. For this reason, many clinicians use speech or other broadband signals in testing. One of the great dangers of accepting an obvious response to a sound with a broad acoustic spectrum lies in the fact that many children with hearing loss have reasonably good sensitivity in some frequency ranges and impaired sensitivity in other ranges. Many children, for example, have sharply falling high-frequency hearing losses and respond quite overtly to sounds containing low-frequency energy like the clapping of hands or the calling of their names. In addition, there is a smaller but significant number of children who have congenital low-frequency sensory/neural hearing losses (Ross & Matkin, 1967).

7. True/False

A positive response to a broadband signal at essentially normal intensities indicates normal hearing.

Ewing and Ewing (1944), pioneers in the testing of young children, used a wide variety of noisemakers, such as bells, rattles, rustling paper, and xylophones to elicit auditory responses. They advocated stirring a spoon in a cup, which produces a soft sound from a child's daily life that may evoke a response when a loud sound does not. Stress on using sounds that are meaningful to the child is most closely associated with the work of the Ewings, although such sounds elicit little in the way of frequency specific information.

Many pediatric audiological procedures involve the child's response to a sound through auditory localization. During the first 6 to 8 months of age, a procedure now known as **behavioral observation audiometry (BOA)** is often employed with two clinicians working together. While one clinician may sit in front of the child, who may be seated on the parent's lap, to occupy the child's attention, the second clinician, located behind and to the side of the mother, presents a variety of sounds. Phonemes such as S, S, S, S or a variety of toys or noisemakers may be used. Crinkling cellophane or onionskin paper makes the sort of soft, annoying sound that is extremely useful in techniques such as these, but like most noncalibrated sounds, provides little or no information about the configuration of the hearing loss.

8. Most BOA procedures rely on a child's ability to ____.

For a sound to be localized, hearing thresholds must be similar in both ears, although not necessarily normal. As a child's ability to localize sound matures, it progresses from eye and head movement seen horizontally, then vertically, then on an arc and finally in a direct line to the sound source (Figure 8.2). If a child does not turn to locate a sound by the age of 8 months, it can be suspected that something is wrong, although not necessarily hearing loss. Mental disability and some childhood symbolic disorders may manifest themselves in a similar lack of response.

If a child cannot be tested by using formal methods, an imitation of vocalization can be tried. The clinician can babble nonsense syllables, without the child watching, to see if the child will imitate. If imitation does take place, it indicates that hearing is good enough to perceive voice. If no response is noted and the clinician babbles again in the child's line of vision, the child with a severe hearing impairment may attempt to imitate, but may do so without voice. This is a most important diagnostic sign. In addition to being a strong indication of hearing loss, silent imitation indicates that the child's perceptual function is probably intact. If the child vocalizes, the voice quality can be evaluated. Although the vocal quality of individuals with hearing loss is sometimes different from that of those with normal hearing, it must be remembered that the voice of the very young child who has a hearing impairment frequently cannot be differentiated from that of the child with normal hearing.

It is possible to observe a child's reaction to the examiner's imitation of the child's sounds. In this case the examiner gives a response to the child's babbling or other vocalizations. A child with normal hearing may cease vocalization and may sometimes repeat it. There are instances in which this procedure works when nothing else does, as the child may stop and listen, the interpretation being that the examiner's voice was heard.

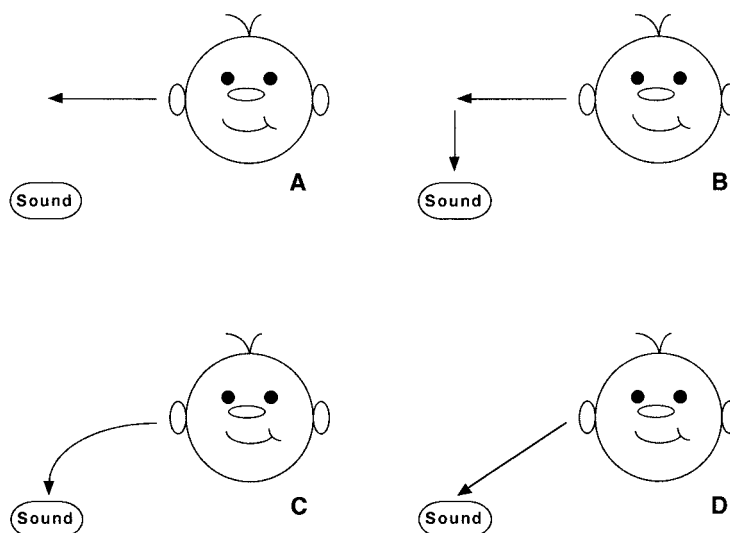


FIGURE 8.2 Development of auditory localization in infants. (A) At 3 months the head moves somewhat jerkily along a horizontal plane. (B) At 5 months localization is in straight lines, first horizontally and then vertically. (C) At 6 months the head and eyes move in an arc toward the sound source. (D) At 8 months the eyes and head move directly to the sound source.

Sound-Field Audiometry

Several approaches for the testing of infants use multiple loudspeakers in a sound-field situation. Recordings of animal noises and baby cries have been effective in eliciting responses, even when filtered into narrow bands. Although a sound such as a whistle, bell, drum, or some vocal utterance may appear subjectively to represent a specific frequency range, this often turns out not to be true. What may seem to be a high-pitched sound may have equal intensity in the low- and high-frequency ranges, as verified by spectral analysis.

Several kinds of responses may be observed when sounds are presented to a child from different directions in the sound field. The child may look for the sound source, cease ongoing activity, awaken from a light sleep, change facial expression, or offer a cry or other vocalized response. Once again, a response to sound has considerable significance, whereas a lack of response is not necessarily meaningful. A useful setup for sound-field localization is shown in Figure 8.3.

Frequently, children will respond to the off-effect of a sound but not to the on-effect. Evaluation of responses to the cessation of sound often goes well with the use of noisemakers, but it can be adapted to sound-field audiometry. A high-intensity pure tone or narrow noise band can be introduced for a minute or so and then abruptly interrupted. This interruption may produce a response, whereas the initial presentation of the sound will not.

It is generally the case that at age 2 months a soft voice begins to become a better stimulus than a loud voice. At 1 to 3 months, percussion instruments are best at eliciting APRs, startle responses such as the **Moro reflex**,² and overall increases in activity or crying. At 4 months, percussion instruments are less successful than they were earlier, but the human voice gains in effectiveness. By 6 months of age much reflex activity begins to disappear.

A potential problem, present whenever screening responses involving high-intensity stimuli are used, is the effect of loudness recruitment on startle responses. If recruitment is present, a child could conceivably respond to a sound as if it were loud, when in fact it might be only slightly above auditory threshold. If this occurs, a child with a cochlear hearing loss with loudness recruitment may pass early screening tests because of the very nature of the disorder. The criteria for minimum response level may be very different for children with hearing impairment. Certainly, if OAEs can be successfully attained, concerns such as this can be circumvented.

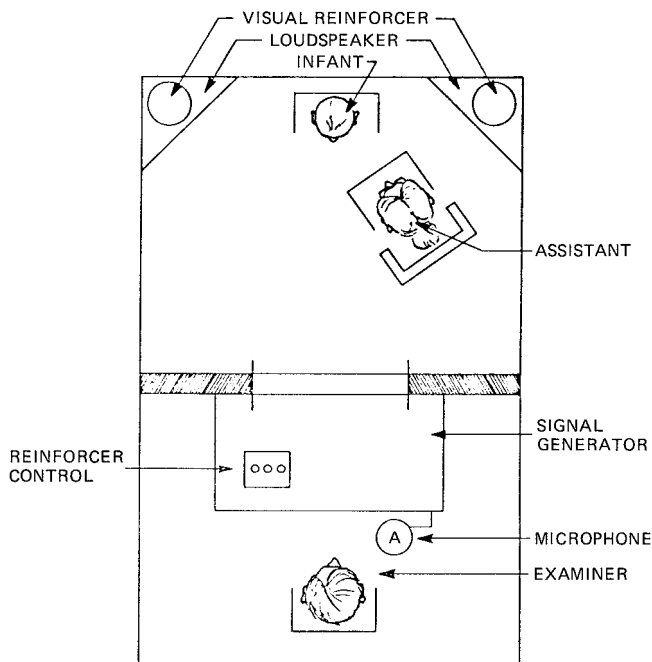


FIGURE 8.3 Diagram of a room useful for sound-field localization tests with small children. (Adapted from F. N. Martin, *Hearing Disorders in Children*, p. 201, © 1991. Reproduced by permission of Pearson Education, Inc.)

Relying on the localization ability of normal-hearing babies more than 4 months old, Suzuki and Ogiba (1961) developed a sound-field procedure called **conditioned orientation reflex (COR)**. A child is seated between and in front of a pair of loudspeakers, each of which holds an illuminated doll within the child's peripheral vision. Pure-tone and light introductions are paired; after several of these paired presentations, the child will begin to glance in the direction of the light source in anticipation of the light whenever a tone is presented. The introduction of the light may then be delayed until after the child has glanced at the speaker; this can serve as reinforcement for orientation to the signal. This procedure works well with some small children and has been modified in several ways, including the puppet in the window illuminated (PIWI) procedure (Haug, Baccaro, & Guilford, 1967).

Rewarding children's auditory responses with visual stimuli has led to the use of **visual reinforcement audiometry (VRA)** (Liden & Kankkonen, 1961). The reinforcer may be anything including a light, a picture, or an animated toy, as long as it evokes the children's interests. Schmida, Peterson, and Tharpe (2003) report that projected video images may be one of the best reinforcers for sustaining localization responses. VRA works with earphones, if the children will tolerate them, as well as in the sound field, with or without hearing aids. Many young children will tolerate insert earphones much more readily than supra-aural earphones. Speech as well as tones may serve as signals. It can be expected that responses to VRA may be obtained from children whose corrected age (chronological age minus the estimated number of weeks of prematurity, if any) reaches 6 months (Moore, Thompson, & Folsom, 1992). A decrease in appropriate responses due to boredom can be avoided by changing the reinforcer as needed to hold the child's attention.

Sound-Field Test Stimuli

Audiologists do not completely agree on the best acoustic stimuli for testing small children. Many, but not all, authorities believe that pure tones are probably not the ideal stimuli, because they are not meaningful to children. Pure tones have the obvious advantage of supplying information

about children's hearing sensitivity at specific frequencies. If, however, a child shows no interest in pure tones, other carefully controlled acoustic stimuli may be used.

The justification for narrowband filtering of a signal for a small child is obvious, and many clinicians use the narrowband noise generators on their clinical audiometers. The belief is that this provides specific frequency information if the child responds. Such an approach may be very misleading. The narrow bands on many audiometers are not very narrow at all, and they may reject frequencies on either side of the center frequency at rates as little as 12 dB per octave. This allows sufficient energy in the side bands to produce a response when a child has not heard the frequency in the center of the band. A variety of sound effects (e.g., cow mooing, bird singing, glass shattering) subjected to steep-slope filtering can be useful with very young children as well as older children and adults with special needs (Abouchacra & Letowski, 1999). It is obvious that audiologists must understand the nature of the equipment they use, and if they elect to test with narrow bands or filtered sounds, they should ascertain for themselves just what the bandwidths are.

Clinical Commentary

Over a quarter of a century ago, Jerger and Hayes (1976) advanced the need to cross-check results obtained in a pediatric evaluation with a separate independent measure. Interpretation of results of behavioral observation audiometry can be quite subjective, and clinical decisions on the validity of responses to VRA and COR testing may rely heavily on the clinician's judgment when frequent random movements are noted from an active child. It is the audiologist's role to provide an accurate assessment of a child's hearing status to avoid misdiagnosis and subsequent mismanagement of the child with hearing loss. Behavioral results should be consistent with cross-checks available from acoustic reflexes and OAEs. When they are not, further investigation is necessary. On occasion, these measures cannot be attained due to active middle-ear pathology or patent ventilation tubes. If the child's history or parental concerns raise suspicion of hearing loss, behavioral results that otherwise appear normal need to be repeated as soon as middle-ear function has been fully restored, or referral should be made for ABR testing. The cross-check principle mandates that no test, regardless of how reliable it is felt to be, should be relied upon until it is substantiated by other tests.

Behavioral Testing of Children Approximately 2 to 5 Years of Age

9. A child with hearing loss and no co-existing handicaps can often be tested using behavioral audiometric procedures before _____ years of age.

At 2 to 3 years of age, children who have no problems other than hearing loss can often be taught to respond to pure tones, especially warble tones. For this reason, awareness tests with voice, whispers, pitch pipes, and other special stimuli may begin to take a back seat in the evaluation process as clinicians will increasingly rely on test stimuli with greater frequency specificity and procedures that more closely approximate true threshold responses.

Early reports in the literature on testing children indicated that it was not possible to get pure-tone threshold responses from children under 5 years of age. It is now quite

common to test children age 3 years or under. It is naturally necessary to work rapidly and smoothly to keep such a young child's attention and cooperation. A child with a "pure" hearing loss (i.e., no other significant problems) should be testable well before 3 years of age.

Speech Audiometry

In spite of the goal to obtain frequency specific auditory responses, behavioral assessment with children will frequently begin with speech audiometry. Speech audiometric procedures permit a greater interplay between the audiologist and child, allowing for the establishment of the requisite rapport needed for subsequent pure-tone testing. Some children will not respond to pure tones, and by their almost stoic expressions, it appears that they cannot hear. A large number of these children can be conditioned to respond to speech signals. If they possess the appropriate language skills, many children will point to parts of their bodies or to articles of clothing. If this kind of response can be obtained, the clinician can recite a list of items to which the child points. The level of the signal can be raised and lowered until speech threshold is approximated.

Often even small children can be tested using adult-like stimuli. Sometimes only an estimate of speech-detection threshold (SDT) can be observed, but when this happens interpretation must be made very judiciously. The normally expected difference of about 10 dB between the SDT and the speech-recognition threshold (SRT) may be exceeded in cases of precipitous high-frequency hearing loss, thereby underestimating a child's true hearing loss. Valuable time may be lost in correct diagnosis in such cases.

Pictures or objects that can be named with spondaic stress can be used to test children. A child will often point to a cowboy or hot dog. The clinician may first demonstrate the procedure and then reward the child's appropriate behavior with a smile, a nod, or a wink. SRTs can frequently be obtained with pictures by age 2 years. Speech-recognition tests designed for children, as described in Chapter 5, may be accomplished in the same way.

Speech audiometry is often possible with children, even when they have very severe hearing losses. Use of the Ling Six Sound Test (Ling, 1989; Ling & Berlin, 1997) can provide frequency-specific hearing-loss information even when reliable tonal responses cannot be attained. The six sounds /a/, /u/, /i/, /S/, /s/, and /m/ are representative of the speech energy contained within all the speech sounds of English. In particular, audibility of /a/, /u/, and /i/ indicates usable hearing through 1000 Hz; audibility of /S/ suggests hearing through 2000 Hz; and audibility of /s/ indicates hearing through 4000 Hz. How well children can recognize those phonemes, and the formant frequencies they represent, can illustrate how well a hearing aid may meet their acoustic needs. At times the Six Sound Test is the only speech measurement that a child can or will perform. It is most useful when carried out in conjunction with other speech and pure-tone audiometric procedures.

The child may also be tested by asking such questions as "Where is Mommy?" or "Where are your hands?" The question "Do you want to go home now?" often evokes a clear response, but it should be reserved as a last resort, for if children do hear that question, it may become impossible to keep them longer. Often a whisper may cause 2- or 3-year-old children to whisper back. If they can hear their own whisper, this may indicate good hearing for high-pitched sounds.

Speech audiometry has revealed hearing abnormalities, or their absence, in children who were unable or unwilling to take pure-tone tests. This has resulted, in many cases, in a substantial savings of time in initiating remedial procedures. Of course, failure of

10. Nonverbal children may be tested using speech audiometry by having them _____.

children to respond during speech audiometry may occur because they do not know what the item (picture or object) is, rather than because they have not heard the word. The clinician should ask the adults accompanying their children to the examination whether specific words are in the children's vocabularies. It is essential to assure that it is word-recognition ability and not receptive vocabulary that is being tested.

Pure-Tone Audiometry

Many times, in testing small children, the problem is to get them to respond. The ingenuity of the clinician can frequently solve this problem. For a child to want to participate, usually the procedure must offer some enjoyment. Some children, however, are so anxious to please that they deluge the clinician with many false positive responses on pure-tone tests, so that it is difficult to gauge when a response is valid. In such cases, slight modifications of adult-like tests may prove workable with some older children. A child may be asked to point to the earphone in which a tone is heard. The ears may be stimulated randomly, and in this way the appropriateness of the response can be determined. The same result may be achieved by using pulsed-tone procedures, asking the child to tell how many tones have been presented.

Operant Conditioning Audiometry

Many times it appears that no approach to a given child will produce reliable results. This is particularly true of children with mental disability. However, Spradlin and Lloyd (1965) suggested that given sufficient time and effort, no child is "untestable," and they recommend that this term be replaced by the phrase *difficult to test*.

In **operant conditioning audiometry (OCA)**, food is often used as a reward for proper performance. A child may be seated in the test room before a table that contains a hand switch. Sounds are presented either through the sound-field speaker or through earphones. The child is encouraged to press the switch when the sound, which can be either a pure tone or a noise band, is presented. If the child's response is appropriate, a small amount of food, such as a candy pellet, or a token is released from a special feeder box. Once children see that pressing the switch will result in a reward, they will usually continue to press it in pursuit of more. It is essential that the switch that operates the feeder be wired in series with the tone-introducer switch so that no reward is forthcoming without presentation of the sound. In this way the child gets no reinforcement for pushing the switch unless a tone is actually introduced and, presumably, heard. Signals that are thought to be above the child's threshold must be introduced first, after which the level may be lowered until threshold is reached. If severe hearing loss is suspected, a good starting point is 500 Hz at 90 dB HL because there is a strong likelihood of hearing at this frequency and level.

Operant conditioning audiometry requires much time and patience if it is to work. Often, many trials are required before the child begins to understand the task. As in other audiometric procedures, it is essential that the signals be introduced aperiodically, for the child may learn to predict a signal and to respond to a sound that has not been heard. Often operant conditioning audiometry can be successful when other procedures have failed. The term **tangible reinforcement operant conditioning audiometry (TROCA)** was coined by Lloyd, Spradlin, and Reid (1968) to describe specifics of operant conditioning to audiometry.

For a number of years clinicians have been using *instrumental conditioning* in testing younger children—that is, teaching the children to perform in a certain way when a sound is heard. This requires a degree of voluntary cooperation from the children, but the clinician can select a method that will evoke appropriate responses.



FIGURE 8.4 A young child with a hearing impairment whose speech thresholds are being tested in the sound field. The clown serves as a device for delivering a tangible reward (candy pellets) when the part of the clown named by the clinician is pressed by the child.

A number of devices for operant audiometry have been described in the literature dating back to the earliest years of audiology. The peep show (Dix & Hallpike, 1947) gives children the reward of seeing a lighted picture when they respond correctly to a tone presented through a small loudspeaker below the screen. The pediacoumeter (Guilford & Haug, 1952) works on a similar principle, except that the child may wear earphones to increase the accuracy of the test. If the child hears a tone and responds correctly by pushing a button, one of seven puppets pops up to startle and amuse. Similar approaches have been used with animated toys, pictures, slides, motion pictures, and computers.

11. OCA works best when the reinforcement is _____.

Martin and Coombes (1976) applied the principles of operant audiometry to the determination of speech thresholds. A brightly colored clown was devised whose body parts (e.g., hand, mouth, nose, leg) were wired to microswitches that triggered a candy-feeder mechanism (Figure 8.4). Children were shown how to touch a part of the clown. Reinforcement of the correct response was the immediate delivery of a candy pellet to a cup, which was momentarily lit in the clown's hand. Preprogramming of the proper switch on a special device in the control room ensured that false responses would not be rewarded. Speech thresholds were obtained on very young children in a matter of several minutes. Weaver, Wardell, and Martin (1979) found this procedure for obtaining speech thresholds useful with children with mental disability.

Play Audiometry

Often, using elaborate devices and procedures to test the hearing of young children is unnecessary (Figure 8.5). Many can simply be taught by demonstration to place a ring on a peg, a block in a box, or a bead in a bucket when a sound is introduced. The more enthusiasm the clinician shows about the procedure, the more likely the child is to join in. Children seem to enjoy the action of the game. Tones can be presented through earphones if children will tolerate them, or through the sound-field speaker if they will not. Many children will readily accept insert receivers because they are light and do not encumber movement. As has been discussed earlier, insert receivers increase interaural attenuation, which often decreases the need for masking and



FIGURE 8.5 A small child taking a voluntary pure-tone hearing test. Use of insert earphones increases interaural attenuation, thereby decreasing the need for masking.

minimizes the possibility of overmasking in most cases. Any time testing is completed using sound-field speakers, the examiner cannot know which ear has responded.

One problem in using play audiometry is to find suitable rewards for prompting the children to maintain interest and motivation in the test. DiCarlo, Kendall, and Goldstein (1962) felt that conditioning in audiometry depends on the following: (1) motivation, (2) contiguity (getting the stimulus and response close together in time and space), (3) generalization (across frequency and intensity), (4) discrimination (between the stimulus and any background activity), and (5) reinforcement (conveying to children that they are doing what is wanted).

The probable reason that some clinicians do not embrace play audiometric techniques is that they feel these techniques can easily become boring to children, and conditioning will therefore

Clinical Commentary

It often becomes apparent to a clinician that a limited amount of time is available to test a small child and that, even though some reliable threshold results are forthcoming, the test should best be abbreviated before the child ceases to cooperate. In such cases, it may be advisable to test one frequency in each ear by air conduction and, if immittance measures were not normal, by bone conduction. This will provide information about the relative sensitivity of each ear and the degree of any conductive component revealed through immittance testing. If an SRT is obtained that suggests normal hearing, the frequency to be tested may be a higher one, say 3000 or 4000 Hz, to make certain that the normal SRT does not mislead in cases of high-frequency hearing loss. If only three to six thresholds are to be obtained, it is often more meaningful to get readings at one or two frequencies in each ear by both air and bone conduction (assuming bone-conduction testing is being done due to abnormal immittance measures) than to obtain six air-conduction thresholds in one ear. Accurate threshold readings at only 500 and 2000 Hz will give some evidence of degree, configuration, and type of hearing loss.

extinguish rapidly. This is probably a case of projection of adult values, since many alert children can play the “sound game” for long periods of time without boredom. When asking children to move beads or other objects from one container to another, it is a good idea to have a large supply on hand. Many children will refuse to play further once the first bucket has become empty, even if they have appeared to enjoy the game up to this point.

Sometimes it is impossible, for a variety of reasons, to teach a child to take a hearing test in one session. In such cases the child should be rescheduled for further testing and observation. It is often worthwhile to employ the talents and interests of the child’s parents or other adults. They can be instructed in methods of presenting sounds and evoking responses. Children may also be more amenable to training in the comfort and security of their homes than in the strange and often frightening environment of sound-treated rooms. One parent may use a noisemaker, such as a bell, in full view of the child, while the other parent responds by dropping a block in a bucket or by some other enjoyable activity. Children can be encouraged to join in the game and, after beginning to participate by following the parents’ lead, can be encouraged to go first.

Once they participate fully, the sound source can be gradually moved out of the line of vision so that it can be determined that responses are to auditory, and not visual, stimulation. A few minutes a day of such activities may allow the audiologist at the next clinic appointment to use the same procedure, preferably with the same materials, which are already familiar to the child. After professional observation of the child’s responses, the audiologist can substitute other sound stimuli in an attempt to quantify the hearing loss, if any. It has also been found useful to have the parents borrow an old headband and set of earphones to accustom the child to wearing them without fear. Similarly, parents can be given a set of foam-style noise reduction earplugs to use with the child at home so the child may become better acquainted with what insert receivers will be like during subsequent testing.

12. Accurate threshold readings at only _____ and _____ can frequently give a good indication of degree and configuration of hearing loss.

Clinical Commentary

Small children’s failure to produce observable responses to intense sounds during informal testing may or may not be due to profound hearing loss. The lack of response during formal testing, such as pure-tone audiometry, may mean either that the children have not heard the sounds or that they have not responded correctly when they have heard them. Deciding between these two possibilities is often difficult. It is sometimes advisable to teach children to respond to some other stimulus, such as to a light, or to the vibrations of a hand-held bone-conduction vibrator set to deliver a strong low-frequency tone. If a child can be taught to give appropriate responses to one sensory input, the inference is that the child can be conditioned to respond, and that lack of response to a sound probably means that it was not heard.

Electrophysiological Hearing Tests

It has been obvious for some time that objective tests for measuring hearing in young children are highly desirable. Thus, there has long been a search for a clear electrophysiological measure of hearing sensitivity to employ when other measures of hearing are inconclusive. Past electrophysiological tests have monitored changes in pulse rate, respiration, heart rhythm, and skin resistance.

13. True/False

When testing a child using ABR or ASSR, it is important that the child remain alert yet quiet.

Procedural limitations and poor reliability have precluded these attempts at electrophysiological assessment from gaining popularity in the assessment of children.

Electrophysiological tests today for the assessment of hearing thresholds primarily involve auditory evoked potentials through auditory brain-stem response (ABR) audiometry and the auditory steady-state response (ASSR) as discussed in some detail in Chapter 7.

A primary advantage to these objective measures is that the procedures are effective during sleep. Many small children will sleep naturally during ABR testing or may be anesthetized with no effects on test accuracy.

Clinical Commentary

In all audiological measures, efficiency in test administration leads to the greatest degree of success. This may be especially true in ABR testing with young children, because results must be attained before the child awakes from either natural or sedated sleep. An efficient ABR test protocol for children is to begin binaurally. If testing must end following determination of a binaural ABR threshold, one at least knows the threshold for the better-hearing ear. If, on the other hand, one starts monaurally and happens to choose the poorer ear, approximation of the child's best hearing may not be attained if the child wakes before the other ear's testing is completed. Once a binaural threshold has been attained, testing can proceed at the observed response level in each ear individually. One of the advantages of ABR testing is the ability to differentiate the type of hearing loss; however, it is limited in threshold determination beyond approximately 80 dB HL. ASSR measures complement ABR testing when estimating thresholds for more severe hearing losses.

There is little doubt that continuing research brings us closer to the goal of an efficient and reliable index of auditory function in uncooperative children. Until that goal is reached, audiologists will still have to confirm their findings with behavioral tests, sometimes only attained through repeated attempts at testing. It should be assumed that the diagnosis is never complete until a voluntary hearing test is obtained from the child, although such is not always possible in cases of concomitant handicap. However, the absence of a full voluntary hearing test cannot be construed as reason to delay (re)habilitation when the presence of hearing loss has been determined through electrophysiological measures.

Clinical Commentary

Most often the presence of normal OAE and normal immittance measures, even in the absence of a full behavioral audiogram, can eliminate referral for ABR/ASSR testing that may have otherwise been necessary. Such practice is not only more economical in time and testing expense, it circumvents the need to otherwise sedate a child whose ABR results would have proven normal. ABR and ASSR are special tests reserved for those instances in which the presence of hearing loss is suspected based on the objective measures of OAE and immittance, yet clear indications of hearing level cannot be ascertained through behavioral approaches.

Language Disorders

Small children are frequently seen in audiology centers because they show some deficiencies in the normal development of speech and language. Because language and speech depend on interactions between the peripheral and central nervous systems, a detailed history must be taken. Special attention should be paid to such things as onset of different kinds of motor development, the age at which meaningful speech or an alternative communication system was acquired, social development, communication of needs, and pre- and postnatal developmental factors. Pertinent data should also include prenatal diseases, the length of the pregnancy, difficulties at birth, and early distress—seen, for example, in cyanotic (“blue”) babies, in babies with jaundice, and so on. Notations should be made of childhood illnesses, especially those involving high or prolonged fevers, and medications taken. Attention should be paid to any illnesses or accidents and any regressions in development associated with them. Some objective data may be obtained from tests of hearing, symbolic behavior, intelligence, and receptive and expressive language.

A young child’s unwillingness to cooperate may be common to all sensory modalities and could indicate a disorder or combination of disorders other than hearing loss (e.g., mental disability or emotional maladjustment). If a child does not respond to visual stimuli such as lights or shadows or to touching or vibration, one might wonder whether the problem is in fact behavioral. However, if a positive response is obtained in one modality and a negative one in another, a certain patterning appears, which is more significant than a generalized response (or lack of response).

Although long lists of possible causes for significant language delay have been postulated, such delay is usually produced by hearing loss, some congenital or early acquired symbolic disorders, attention deficit hyperactivity disorder (ADHD), mental retardation, emotional disturbance, or **autism**. A common error committed by clinicians is to consider causes as an either-or condition and to attempt differential diagnosis to rule out all but one cause. The experienced clinician will have observed that the presence of one significant disorder increases, rather than decreases, the probability of another.

When a small child has a language disorder, and hearing loss cannot be eliminated as a possible causal factor, the resources and experience of the clinician are called on for an appropriate diagnosis. The behavioral characteristics of the clinical entities mentioned here can frequently be ruled out on the basis of observation of behavior and developmental history. The problem then remains to differentiate between the hard-of-hearing and the otherwise language-disordered child. Even though the child with brain injury is said to manifest such symptoms as impatience, hyperactivity, poor judgment, **perseveration**, and **dysinhibition**, often there is a symbolic disorder without the presence of bizarre behavior.

Audiologists frequently see children who are either believed to have hearing losses or whose auditory behavior is so inconsistent as to cast doubt on the presence of normal hearing. A parent or teacher may complain that a child’s responses to sound are inconsistent, that performance is better when background noises or competing messages are at a minimum, and that it is possible that the child “just doesn’t pay attention.” Sometimes auditory test results appear normal on such a child, and the parents are mistakenly assured that all is fine. The audiologist must constantly be alert for auditory-processing disorders that can coexist with other learning and language disabilities. Screening tests are needed so that children with auditory processing disorders, however mild, will not be overlooked, but will be properly referred to the proper specialists, such as speech-language pathologists, for complete diagnosis

14. Does the identification of one disorder increase or decrease the likelihood that a second disorder co-exists with the first?

and therapy (Martin & Clark, 1977). Many of the tests for auditory processing disorders, described in Chapter 12, can be performed accurately on children as young as 6 years old.

In the final analysis, the diagnosis of the “difficult case” must often be made subjectively by a highly qualified, experienced examiner. Despite the initial diagnosis, it must be remembered that, until peripheral hearing status has been deemed normal through behavioral or objective measures, hearing loss cannot be ruled out as a possible contributory element.

Auditory Processing Disorders

Recent years have brought a focus on an auditory disorder in children with otherwise normal hearing sensitivity or whose effective use of audition is impeded by more than the detrimental effects expected from peripheral pathology alone. The earlier term *central auditory processing disorder* has appropriately been replaced by the term **auditory processing disorder (APD)**, a term that may emphasize the interactions of disorders at both peripheral and central sites without necessarily attributing difficulties to a single anatomical locality (Jerger & Musiek, 2000). “Auditory processing disorder” is often applied to children whose recognition or use of language is not age-appropriate, and/or is inconsistent with their level of intelligence. Many of these children also have additional learning disabilities that prevent them from progressing normally in their education.

APD has been estimated to occur in 2 to 3% of children, with occurrence twice as likely in boys (Chermak & Musiek, 1997). Since APD has become recognized, it may be a favored diagnostic category, and there may be reason to be concerned that overdiagnosis of this condition may occur, leading to inappropriate educational methods. Accurate diagnosis of APD is based upon a multifaceted, comprehensive assessment, which includes input from audiologists, speech-language pathologists, psychologists, and educators.

Children with APD, despite normal intelligence, often have poor listening skills, short attention spans, seemingly poor memories and reading comprehension, difficulty in linguistic sequencing, and problems in learning to read and spell. One of the most frequently reported dysfunctions is difficulty in recognizing speech in the presence of background noise. Deficits related to auditory processing difficulties contribute to delays in speech and language and poor performance in school. As a result, these children may suffer from lowered self-esteem, which further complicates the disorder. Many children with auditory processing disorders make inappropriate social contacts, since their failures with children in their age group lead them to seek playmates who are younger than they are. Often parents and other adults report that these children prefer to play alone.

Intervention is aimed at improving listening skills and spoken language comprehension through a multi-strategy approach. This may include enhancement of the signal-to-noise ratio in the listening environment through preferential seating in the classroom; reduction of background noise and reverberation through acoustic modifications and often the use of FM systems (see Chapter 14); auditory skills training; and development of **metalinguistic training** and **metacognitive training** strategies (Chermak & Musiek, 1997). Additional discussion of APD management may be found in Chapter 15.

For communicating with other professionals, such as teachers, technical diagnostic statements are less useful than those that describe the kinds of difficulties a child may have in learning and suggestions for specific remedies. Diagnostic entities such as APD, ADHD, dyslexia,

15. One intervention for children in school with APD is _____.

emotional disturbance, and so on may be more threatening than useful to professionals who must assist these children. Suggestions for a more structured learning environment can be a useful addendum to reports to the classroom teacher (Clark, 1980; Hall & Mueller, 1997).

A list of suggestions for the classroom teacher of a child with auditory processing disorder may be found in the Handouts section under Professional Resources on the Companion Website.



Auditory Neuropathy in Children

It is probably the case that auditory neuropathy is rare in children, although this is controversial. Symptoms include mild-to-moderate sensory/neural hearing loss, abnormal or absent ABRs, absent or markedly elevated acoustic reflexes, and normal OAEs. The presence of OAEs strongly indicates that the lesion in these cases is medial to the cochlea. Amplification with hearing aids is met with mixed success, and many experts urge the use of signs for the teaching of language.

Psychological Disorders

Hearing loss that is congenital or acquired early in life can have an effect on social, intellectual, and emotional development, including “egocentricity, difficulty in empathizing with others, rigidity, impulsivity, coercive dependency, and a tendency to express feelings by actions rather than by symbolic communication” (Rose, 1983). As a child without normal hearing continues to develop, the normal parent–child relationship is invariably affected, lending further justification for intervention at the earliest possible time.

Developmental Disabilities

Children with developmental disabilities may include those with mental disability, cerebral palsy, epilepsy, autism, or a wide variety of physical or mental challenges. While a high percentage of children with developmental disability have cognitive impairments as well, many have normal or greater than normal intelligence. Hearing loss among these children may go undetected because behaviors of auditory inattention may be attributed to the child’s more overt handicap.

Evaluation of children with developmental disabilities presents a true challenge to the audiologist. Responses from children who are profoundly multidisabled may be more reflexive than representative of true attention behaviors (Flexer & Gans, 1985). Such responses may be better evaluated in the context of the child’s developmental age than his or her chronological age. Hearing may be considered normal if the development of auditory responses is generally consistent with the age level of the child’s other developmental behaviors. This judgment becomes more difficult if the child’s cognitive and developmental ages have not yet been determined.

The physiologic measures described in Chapter 6 provide a dimension to the evaluation of the difficult-to-test patient that was not available in the past. However, the sometimes ambiguous results of physiologic measures of hearing increase with central nervous system involvement, thereby increasing the value of any behavioral results that may be obtained (Martin & Clark, 1996).

Identifying Hearing Loss in the Schools

The exact number of school-age children who have hearing impairments is not known. Surveys that attempt to come up with figures are also confounded by such factors as geographic location and season of the year; there are more failures during cold weather (Gardner, 1988). It is probable that more than 5% of the public-school population will have a hearing impairment at any given time. This does not count the students enrolled in residential and day schools for children with profound hearing impairments. Clearly, there is a need for screening methods that identify school children with hearing loss.

Equipment accuracy and the use of acceptable workspaces are mandatory in hearing-loss-identification programs. Audiometers should be calibrated annually by a factory-trained technician, with outputs checked on an artificial ear every three months (Patrick, 1987). Of course, if an audiometer or its earphones are jarred or dropped, calibration should be checked before any further hearing tests are done. Listening checks should be performed at the start of every test day, with special attention to breaks in the receiver cords.

Hearing Screening Measures

Early school hearing screenings were conducted in groups, thereby decreasing the demands on personnel, space, and equipment. Problems arising from difficulties in maintaining equipment calibration, and from the many false positive responses from children striving to pass due to fear of nonacceptance, eventually led to discontinuation of group screening measures. School screenings are carried out today on an individual basis. They are usually done by fixing the intensity of the audiometer and changing frequencies. Obviously, screenings may be performed more rapidly if a restricted number of frequencies is sampled and screening is done at a level high enough to be attended to easily by young children. Some authorities have recommended screening only at 4000 Hz because this frequency is often affected by hearing loss. Other people believe that screening with immittance meters will uncover the major source of hearing disorders in the schools: otitis media. It is possible that this approach could catch middle-ear disorders in the early stages, perhaps averting any conductive hearing loss at all. The combination of tympanometry and ipsilateral acoustic reflex screenings is most useful for this purpose. Utilizing a pulsed tone to elicit the reflex has been demonstrated to significantly increase the utility of the ipsilateral acoustic reflex within a screening protocol (Sells, Hurley, Morehouse, & Douglas, 1997). Of course, middle-ear problems are not the only cause of hearing loss in school children.

In 1984, ASHA published guidelines for hearing-loss identification in the schools. Proposed revisions of these guidelines that have since appeared (ASHA, 1993, 1997) state that the goals of such programs are to incorporate acoustic immittance measures with pure-tone audiometry to identify students who are in need of audiological and/or medical services. Patrick (1987) states that 80 to 90% accuracy is obtained when acoustic immittance is combined with pure-tone screenings, as compared to 60 to 70% accuracy when pure tones are used alone. New, automated, portable, easily used immittance screening devices (Figure 8.6) produce a tympanogram and screen for acoustic reflexes on each ear tested in a matter of seconds (Figure 8.7). The most recent ASHA guidelines (ASHA, 1997) are summarized in Table 8.5.

16. Childhood hearing loss identification programs most frequently screen using _____ and _____.



(A)



(B)

FIGURE 8.6 Portable acoustic immittance device in use (A) and with its holder (B), which stores, recharges the unit, and prints the tympanogram and acoustic reflex results (see Figure 8.7). (Courtesy of Clark Audiology, LLC, and Welch-Allyn, Inc.)

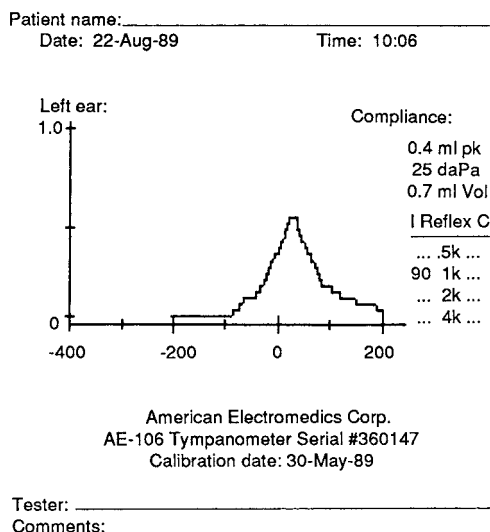


FIGURE 8.7 Printout of a tympanogram and acoustic reflex screening done on a school child with normal hearing.

Testing the Reliability of Screening Measures

For a hearing screening to be useful, it must be both sensitive and specific. The sensitivity of a test may be determined by dividing the number of children with hearing loss who fail the screening by the number who actually have a hearing loss. This yields the percentage of those who have been correctly identified as positive. The specificity of a screening procedure is calculated by dividing the number of children who pass the screening and do not have a hearing loss by the total number who do not have a hearing loss. This is the percentage of true negative results. A comparison of the sensitivity and specificity of a screening test to the overall population with hearing loss determines the predictive value of a screening procedure, which will account for the inevitable over-referrals and under-referrals for follow-up.

TABLE 8.5 Summary of ASHA (1997) Guidelines for Audiological Screening of the Pediatric Population

- 1. Screening for outer- and middle-ear disorders, birth through 18 years
 - A. Combination of visual identification of structural defects of the ear or ear canal abnormalities and tympanometric screening.
 - B. Failure if visual abnormality noted or tympanogram reveals reduced peak admittance (compliance) (<0.2 mmho for infants / <0.3 mmho for one year to school age / <0.4 mmho for children > 6 years of age) or tympanometric width >235 daPa for infants or >200 daPa above one year.
 - C. Immediate medical referral for otalgia or otorrhea or tympanometric findings consistent with TM perforation. Otherwise rescreen within 6 to 8 weeks for failed tympanogram.
- 2. Hearing-impairment screening for birth to 6 months of age
 - A. Recommend screening in quiet or sleeping state with ABR or OAE.
 - B. Refer in absence of reliable response in either ear with confirmation of auditory status within 1–3 months.
- 3. Hearing-impairment screening for 7 months to 2 years of age
 - A. When can condition to VRA screen with earphones (supra-aural or insert) using 1000, 2000, and 4000 Hz at 30 dB HL.
 - B. When can condition to play audiometry screen with earphones using 1000, 2000, and 4000 Hz at 20 dB HL.
 - C. Sound field can be substituted for earphone screening, recognizing limitations.
 - D. OAE suggested as an alternative procedure when behavioral methods are ineffective.
 - E. Screenings failed at any frequency in either ear should be referred for audiologic confirmation of hearing status within 1–3 months.
- 4. Hearing-impairment screening for 3 to 5 years of age
 - A. If can reliably participate in conditioned play audiometry or conventional audiometry, screen with earphones using 1000, 2000, and 4000 Hz at 20 dB HL.
 - B. Screenings failed at any frequency in either ear should be referred for audiologic confirmation of hearing status within 1–3 months.
- 5. Hearing-impairment screening for school-age children, 5 through 18 years of age
 - A. Screen on initial entry to school, entrance to special education, or grade repetition, and annually in kindergarten through 3rd grade and in 7th and 11th grades.
 - B. Screen via conventional audiometry or conditioned play audiometry with supra-aural or insert earphones using 1000, 2000, and 4000 Hz at 20 dB.
 - C. Reinstruct and rescreen within the same screening session in which a child fails.
 - D. Refer all who fail the rescreen or fail to condition to the screening task.
 - E. Screenings failed at any frequency in either ear should be referred for audiologic confirmation of hearing status within 1–3 months.

Note: All referrals for hearing-impairment screening should ensure prompt completion of the diagnostic process and timely initiation of habilitative procedures. Screenings should be completed within appropriate settings as defined within the comprehensive guidelines with calibrated equipment. Screenings may be carried out by support personnel under the supervision of an audiologist.

17. An excellent means of checking the accuracy of a hearing screening program is the use of a _____.

Any screening carries the danger of misclassification. No matter how cleverly a screening measure is designed, it is not possible to determine its shortcomings without submitting it to some empirical verification. A procedure described by Newby (1948) involves the use of a **tetrachoric table** and appears to serve this purpose well (Figure 8.8). One hundred children who have taken the screening are selected at random and given threshold tests under the best possible test conditions. The threshold test serves as the criterion for the accuracy of the screening measure. Cells A and D in Figure 8.8 represent agreement between threshold assessments and screenings, showing correct identification of those children with and without hearing losses. Cells B and C represent disagreement between the two measures; the

		THRESHOLD ASSESSMENT	
		Failed	Passed
SCREENING MEASURE	Failed	A	B
	Passed	C	D

FIGURE 8.8 Tetrachoric table used to validate the efficiency of a hearing screening measure. The children correctly identified as having hearing losses by the screening and verified by the threshold assessment are shown in cell A (true positive). Those properly identified as having no hearing loss are shown in cell D (true negative). Those children with normal hearing incorrectly identified by the screening as having hearing losses are shown in cell B (false positive). Cell C shows the children with hearing losses who were missed by the screening (false negative).

larger the number in those two cells, the poorer the screening is at doing its job. Cell C seems to be the biggest offender, passing children on screenings who fail the individual test, thereby missing their hearing losses. This suggests that the criteria, such as the screening level, are too lax. A large number in cell B shows that time and energy are being wasted by identifying children with normal hearing as having hearing losses. In such cases, screening criteria may be too stringent, failing children who should have passed.

No matter how carefully a screening is conceived, the numbers in cells B and C will probably never reach the ideal zero. If the criteria are so stringent that no child passes who should fail, the penalty is to retest a lot of children with normal hearing, or to make many overreferrals. On the other hand, decreasing the number in cell B at the expense of missing children with hearing losses seems unthinkable.

In the real world, the person in charge of any screening program must balance factors of money, personnel, and the number of children to be tested against the efficiency of the screening measure. There appears to be an inverse relationship between efficiency and accuracy in any screening if one defines “efficiency” in terms of the number of screenings performed with the least expenditure of time and money.

Public school environments for hearing screenings are often less than satisfactory. Often the testing is done in large rooms with poor acoustics and with considerable background noise. Many children may be tested before an audiometer calibration defect is detected. Unless all the criteria for adequate testing are met, the purpose of the procedure is defeated.

The desirability of any hearing screening procedure is obvious. However, screening procedures can be terribly misleading if the strictest criteria are not adhered to. Even at the time of this writing the gold standard for determining hearing loss is the pure-tone audiogram. Procedures like the Calibrated Finger Rub Auditory Screening Test (CALFRASST) (Torres-Russotto et al., 2010) may be attractive as time savers but such tests can easily miss hearing losses, especially losses in the high frequencies, and are not recommended.

Clinical Commentary

Children with total or even partial unilateral hearing loss often go undiagnosed for long periods of time since they obtain their auditory information from their normal ear. Many of these children experience greater academic difficulties than has been previously thought.

Erroneous Hearing Loss in Children

18. Children who feign or exaggerate a hearing loss are said to have _____.

A full discussion of erroneous, or nonorganic, hearing loss may be found in Chapter 13. There are numerous reports in the literature of erroneous (false or exaggerated) hearing losses among children. The causes may range from misunderstanding of the test to malingering to psychogenic disorders. While an erroneous hearing loss may be easily missed in a screening measure, as a general rule, it is not difficult for alert clinicians to detect its presence in children and, with some clever manipulation, to determine the true organic hearing thresholds. The earlier problems related to erroneous hearing loss can be detected, the sooner they can be managed. It is important to quickly eliminate the reliance on a false hearing loss before it becomes a crutch to solve or avoid emotional, social, or academic problems.

Children who exhibit erroneous hearing loss typically do not appear to have hearing difficulty in normal conversation situations and often show normal speech thresholds, despite apparent hearing losses for pure tones. Within the pediatric population, prevalence of erroneous hearing loss will generally be less than 7% (Campanelli, 1963; Maran, 1966). Despite this relatively low prevalence, audiologists must recognize erroneous hearing loss in children when they see it, know how to establish hearing levels, be prepared to talk with parents about the identified behavior, and know when and how to refer for additional psychological consultation (Clark, 2002).

Among adults, the exhibition of erroneous hearing loss may arise from a variety of origins but probably is most frequently rooted in a motivation based upon anticipated financial gain. When erroneous hearing loss appears in children, the underlying motivation is frequently much less apparent. In children, the reasons for displays of erroneous hearing loss are typically an anticipated psychological gain and may be seen when parents divorce or are separated, when there is alcohol or substance abuse in the home, or when there is a sibling with hearing loss.

Although many schoolchildren try diligently to pass their hearing tests, others manifest symptoms of erroneous hearing loss. Ross (1964) has pointed out the dangers of reinforcing children's notions that they have a hearing loss. They may consciously or unconsciously see the advantages of hearing loss and may decide that the risk is worth the secondary gains to be realized in the forms of favors and excuses. Ross advised that children should not be referred to physicians for follow-up examinations unless the person in charge of the school tests is reasonably certain that a hearing problem exists. Most experienced audiologists can probably recall specific incidents in which a child has become committed to continued fabrication of a hearing loss, no matter how the problem got started.

EVOLVING CASE STUDIES

Only Case 4 is included here for obvious reasons. Look at the tests described in this chapter and determine which ones are indicated and best suited to this 3-year-old child. Project what might happen on behavioral tests, including speech audiometry, pure-tone audiometry, operant-conditioning audiometry (OCA), and play audiometry. Conjecture about what might be observed on objective tests that were discussed in Chapter 7, such as acoustic immittance, otoacoustic emissions (OAEs), and auditory brain-stem response (ABR). How would you deal with the obvious language disorder this child exhibits?

Case Study 4: Pediatric Patient

Inclusion of otoacoustic emissions testing is rapidly becoming a standard in pediatric assessments. While some children will respond best if testing begins with the more interactive behavioral measures of hearing, with a skilled and personable clinician it is possible to begin with the more objective measures of OAE, acoustic immittance, and acoustic reflexes. If emissions are normal, conductive hearing loss is ruled out and no worse than a mild sensory/neural hearing loss is present. Given the negative history of middle-ear infections, Type A tympanograms would probably be evinced with essentially normal static compliance measures. Testing for acoustic reflexes (ipsilateral and contralateral) will provide a cross-check with the results of behavioral measures as the diagnostic picture is formed for this child.

Behavioral testing may be addressed next using a team of two audiologists or, if necessary, employing a parent or caregiver as an assistant. Testing with earphones should be attempted, but if the child is at all fearful of these, initial testing should begin in the sound field but should transition to earphones if it appears likely that the child will accept them. Because at this age obtaining a reliable hand-raise response to pure tones is unlikely, using a technique such as conditioned play audiometry would probably be the best choice. If that fails, OCA could be employed. While it might take several sessions, fairly reliable results can probably be obtained and would most likely reveal a severe loss by air conduction of 70 to 90 dB with essentially absent bone-conduction responses. A finding of absent OAEs and absent acoustic reflexes would be consistent with these pure-tone findings. While this child has no language abilities, precluding administration of most speech audiometric measures, determination of speech awareness levels could be made in the same manner that pure-tone thresholds were obtained and should be in agreement with those. If behavioral testing fails, ABR might be necessary, which in this case would reveal absent responses. The auditory steady state response, which can provide responses for more severe and profound hearing losses, should be consistent with a 70 to 90 dB sensory/neural hearing loss.

Even if precise thresholds are not known for several frequencies in each ear, if there is a reasonable probability of hearing impairment, hearing aids should be introduced at the earliest possible time. Modern hearing instruments are extremely flexible and can be adjusted to suit the child's hearing loss as more details are obtained. The child should be entered in a language stimulation program as soon as possible. Further testing is necessary to be certain of the accuracy of test results. More discussion of the management of this little girl's case will be covered in ensuing chapters.

Summary

While pediatric audiology can be stimulating and rewarding, it can also be time-consuming and frustrating. Often clinicians do not have the feeling, as they have with most adults, of complete closure on a case at the end of a diagnostic session. Nevertheless, the proper identification and management of hearing loss in children is one of the most solemn responsibilities of the audiologist. Under ideal conditions children with identified hearing loss should have their hearing tested every six months until stability of the loss is documented and annually thereafter. Truly, work with children is often carried out more as an art than a science, testing the cleverness and perseverance of clinicians, and calling on all their training and experience.

Pediatric audiology includes the use of those tests and diagnostic procedures designed especially for children who cannot be tested by conventional audiometry. Approaches vary with both the chronological and mental ages of children. Some tests, designed merely to elicit some sort of startle reaction, may be carried out on children as young as several hours of age. Other tests

employ play techniques, or use special rewards to encourage proper performance. Still other procedures involve measuring changes in electrophysiological states or electroacoustical properties in response to sound, or the detection of sounds emitted from the ear. With some children it is possible to test by making slight alterations in conventional audiometric techniques used with adults. Hearing testing is designed to determine the nature and extent of a child's communicative problem and is virtually useless unless some (re)habilitative path is pursued, as discussed in Chapter 15.

REVIEW TABLE 8.1 Procedures Used in Pediatric Audiometry

<i>Procedure</i>	<i>Age Group Most Suitable</i>	<i>Probability of Success</i>
Warblet	Infants	Fair
Speech sounds	4 to 8 months	Good
COR, VRA	6 months to 2 years	Good
Imitation of vocalization	Under 1 year	Fair
Play audiometry	2 to 6 years	Good
Operant conditioning	2 to 5 years	Good
Noisemakers	Under 3 years	Fair
Pure-tone audiometry	Over 3 years	Good
AEP	All ages	Very good
OAE	All ages	Very good
Immittance measures	All ages	Very good

Related Website

Boystown National Research Hospital in Omaha, Nebraska, provides a website at www.babyhearing.org with consumer

and professional discussions and resources on a variety of topics related to pediatric hearing loss.

Study Questions

1. What are the first five questions you would ask the parents of a small child being seen for a hearing evaluation?
2. A child under 1 year of age is to be seen for an evaluation. How would you prepare before the child's arrival in the clinic? List the procedures you would use in the order you would use them.
3. Summarize the risk indicators for permanent congenital, delayed onset, or progressive hearing loss in children as outlined by the Joint Committee on Infant Hearing.
4. What are the major steps you would take as an audiologist organizing a school hearing test program? Once begun, how would you test its efficiency?
5. Consider the major causes for the lack of speech development. List some of the typical symptoms for each cause.

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Endnotes

1. Dr. Virginia Apgar, American anesthesiologist, 1909–1974.
2. Named for Ernst Moro, German pediatrician, 1874–1951.

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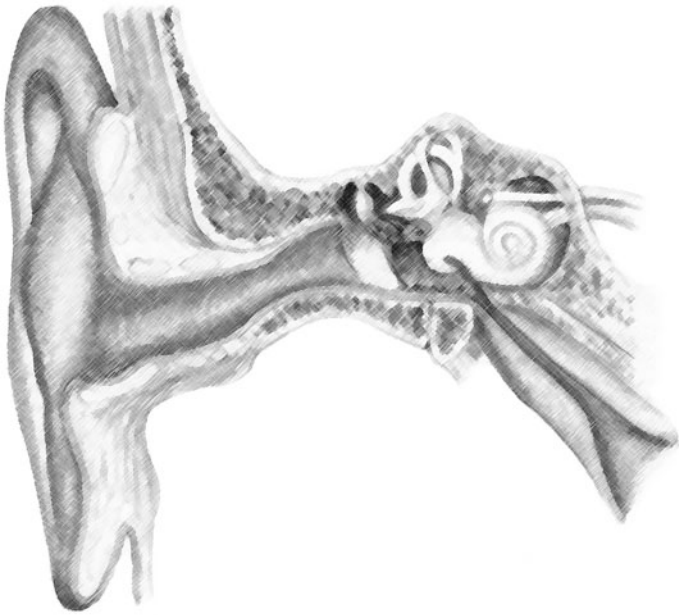
PART III

Hearing Disorders





In Chapters 9 through 12 the description of the auditory system is divided into four separate parts for study of the outer ear, the middle ear, the inner ear, and the auditory nerve and central auditory pathways. The anatomy and physiology are described, as well as different disease processes that produce auditory disorders, their causes, and appropriate treatments. Chapter 13 discusses patients who are either pretending to have a hearing loss or exaggerating the loss they do have for some special gain. Examples are given of actual and theoretical findings on a variety of auditory tests described in Chapters 5 through 8, so that each disorder is exemplified from a diagnostic point of view. Additional tests are described where appropriate.



The Outer Ear

WHEN LAYPERSONS THINK of the “ear,” it is the outer ear that comes to mind. The outer ear is responsible for gathering sounds from the acoustical environment and funneling them into the auditory mechanism. Some of the outer-ear structures found in humans are absent in such animals as birds and frogs, whose hearing sensitivity is nevertheless similar to that of humans. It is, of course, the outer ear of humans with which this chapter is concerned.

LEARNING OBJECTIVES

This chapter requires no previous knowledge of human anatomy, but it does assume an understanding of the physics of sound and the various tests of hearing described earlier. All the minuscule details of the anatomy of the outer ear are not provided here. These may be obtained readily from books on anatomy. Upon completion of Chapter 9, the reader should be able to

- Discuss in basic terms the outer-ear anatomy and its purpose.
- List a variety of common disorders that may affect the outer ear.
- Describe how these disorders are caused and treated and how they may manifest on a variety of audiometric tests.

Anatomy and Physiology of the Outer Ear

The Auricle

The most noticeable portion of the outer-ear mechanism is the **auricle** or pinna (Figure 9.1). The auricle varies from person to person in size and shape, and its funnel-like configuration plays a substantial role in gathering sound waves from the environment. The auricle is made entirely of cartilage, with a number of individually characteristic twists, turns, and indentations. The entire cartilage is covered with skin, which is continuous with the face. The bottom-most portion of the auricle is the lobule, or ear lobe. Extending up from the lobule, the outer rim of the auricle folds over outwardly, forming the helix. Above the lobule is the antitragus. Another elevation running closer to the center of the auricle is the antihelix. A small triangular protrusion, which points slightly backward and forms the anterior portion of the auricle, is called the **tragus**, Latin for “goat’s beard.” The tragus is so named because in older men a number of bristly hairs appear in this region. Depression of the tragus into the opening of the external ear canal is an efficient means of blocking sounds. This occlusion provides more efficiency than plugging the ear with a finger, clapping the hands over the auricle, or even using some earplugs specifically designed for sound attenuation. Although humans cannot voluntarily close off the tragus, as can some animals, vestiges of muscles designed for this purpose remain in the human ear.

The middle-most portion of the outer ear, just before the opening into the head, is called the *concha* because of its bowl-like shape. The concha is divided into two parts, the lower cavum concha, and the upper cymba concha. This portion of the external ear aids in the human ability to localize the sources of sounds that come from in front, behind, below, and above the head. The concha helps to funnel sounds directed to it

1. The main function of the auricle is to _____.



For labeled photos and schematics of the anatomy of the external ear, see “Anatomy” in the Learning Supplements section of the Companion Website.

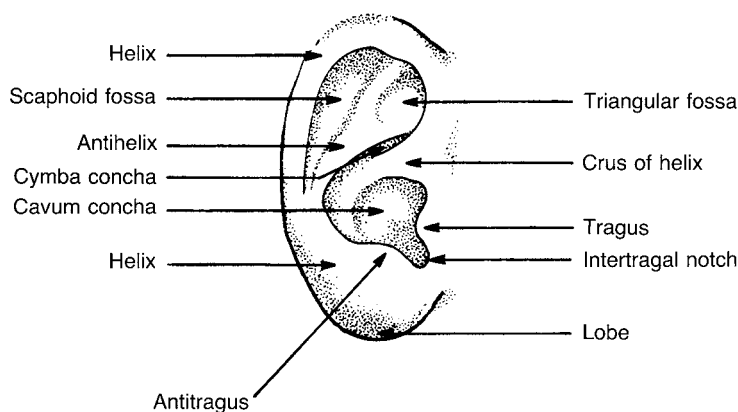


FIGURE 9.1 The human pinna and its primary landmarks (auricle).

1. catch sound and funnel it down the external auditory canal

from the surrounding air into the opening of the **external auditory canal** (EAC), or external auditory **meatus**. The anatomy of the auricle is such that it is more efficient at delivering high-frequency sounds than low-frequency sounds, and it helps in the localization of sounds delivered to the head.

The External Auditory Canal

In discussing this portion of the ear, it is important not to omit the word “external” to avoid confusion with the internal auditory canal, discussed in Chapter 12. The external auditory canal is a tube, formed in the side of the head, beginning at the concha and extending inward at a slight upward angle for approximately 1 inch (2.5 cm) in adults. Although it appears to be round, the EAC is actually elliptical and averages about 9 mm in height and 6.5 mm in width. It is lined entirely with skin (Figure 9.2).

The outer portion of the EAC passes through cartilage. The skin in this area supports several sets of glands, including the sebaceous glands, which secrete sebum, an oily, fatty substance. The major product of these secretions is earwax, or **cerumen**, which is usually soft, moist, and brown, but can be light in color, flaky, and dry, or if accumulated in the ear canal for a protracted period may become quite dark and hard. Cerumen exits the ear naturally when the walls of the EAC are distorted by movement of the jawbone during chewing or speaking. The outer third of the EAC contains a number of hair follicles. The combination of hairs and cerumen helps to keep foreign objects, such as insects, from passing into the inner two-thirds of the canal.

The inner area of the EAC passes through the tympanic portion of the temporal bone. There are no glands and no hair in this area. The two portions of the EAC meet at the osseocartilaginous junction. The **condyle**, a protrusion of the mandible (jawbone), comes to rest just below the osseocartilaginous junction when the jaw is closed. If the mandible overrides its normal position, as in the case of missing or worn molar teeth or a misaligned jaw, the condyle

2. Earwax is
manufactured in
_____.

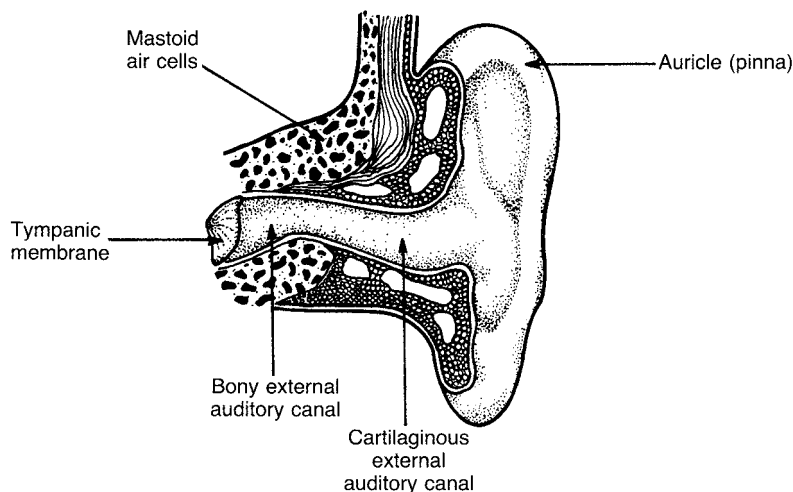


FIGURE 9.2 Cross-section of the external ear.

will press into the junction, causing pain. The term **temporomandibular joint (TMJ) syndrome** has been coined for this neuralgia. The TMJ syndrome produces a referred pain, perceived in the ear, which constitutes a significant amount of **otalgia** (ear pain) in adults.

3. Ear pain in the absence of infection may be caused by _____.

The term *myofascial pain dysfunction (MPD) syndrome* is sometimes used to describe pain in the temporomandibular joint, along with headaches; grating sounds (crepitus); dizziness; and back, neck, and shoulder pain. At times, emotional stress and tension have been associated with MPD syndrome, and treatment has ranged from emotional therapy to biofeedback training, the use of prosthetic devices, and major maxillofacial surgery.

In infants and small children, the angle of the EAC is quite different from that in adults. The canal angles downward, rather than upward, and is at a more acute angle. For this reason, it is advisable to examine children's ears from above the head, rather than from below. When one looks into an ear, the adult pinna is pulled up and back, whereas the child's pinna is pulled down and back.

The EAC serves several important functions. The **tympanic membrane** is situated at the end of the canal, where it is protected from trauma and where it can be kept at a constant temperature and humidity. The canal also serves as a filter to reduce low frequencies and as a tube resonator for frequencies between 2000 and 7000 Hz, thereby creating an efficient transfer of energy to the tympanic membrane.

The Tympanic Membrane. The external auditory canal terminates in a concave, disk-like structure called the tympanic membrane (Figure 9.3). The term eardrum is commonly used to describe this structure, although properly speaking a drum would include the space below a vibrating membrane (in this case the middle ear), and so the term eardrum membrane is more accurate. The tympanic membrane is discussed in this book along with the outer ear because it can be viewed along with the outer-ear structures. Because the tympanic membrane marks the border between the outer ear and the middle ear, however, it is really a common boundary between both areas. Whether the tympanic membrane is thought of as part of the outer ear or the middle ear is not important as long as its structure and function are understood.

The total area of the tympanic membrane is about 90 mm² (Harris, 1986) and is constructed of three layers. The outer layer, as viewed from the external auditory canal, is made up of the same skin that is stretched over the osseous meatus. Below the skin is a layer of tough, fibrous, connective tissue, which contributes most to the membrane's ability to vibrate with impinging sound waves. Behind the tympanic membrane is the middle-ear space, which is completely lined with mucous membrane, including the third layer of the tympanic membrane.

The tympanic membrane is extremely thin, averaging about 0.07 mm. Harris describes it as "a little conical loudspeaker." It is an extremely efficient vibrating surface. Movement of one-billionth of a centimeter is sufficient to produce a threshold response in normal-hearing individuals in the 800 to 6000 Hz range. The entire area of the tympanic membrane is very rich in blood supply, which is why it appears so red when infection is present and blood is brought to the area.

Embedded in the fibrous portion of the tympanic membrane is the **malleus**, the largest bone of the middle ear (described in Chapter 10). The tip of the malleus ends in the approximate center of the tympanic membrane and angles downward and backward (see Figure 9.3).

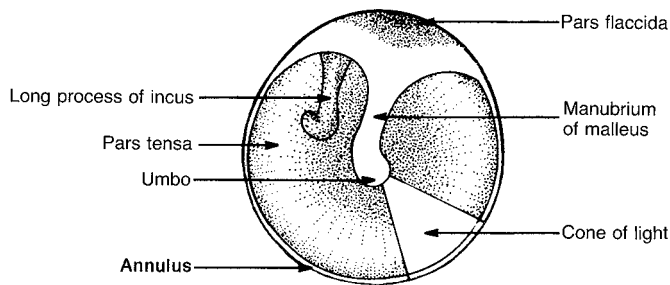
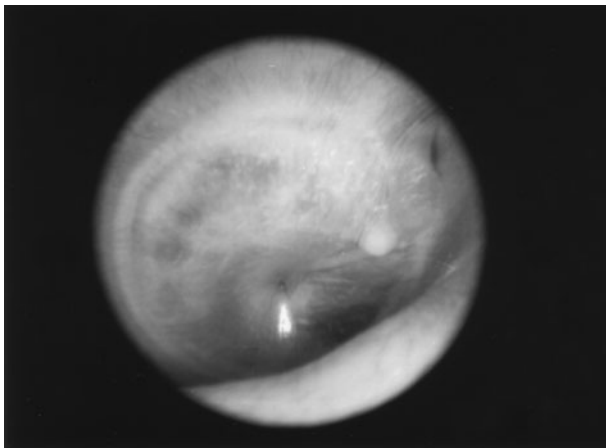
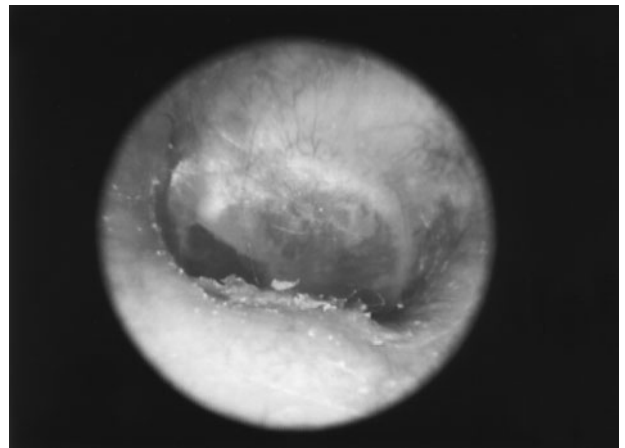


FIGURE 9.3 A right tympanic membrane as viewed through the ear canal. Note the light reflex known as the cone of light appears in the inferior/anterior quadrant of the tympanic membrane.



(A)



(B)

FIGURE 9.4 Normal right (A) and left (B) tympanic membranes (TM). Note the cone of light is clearly visible on the right TM but partially obstructed from view on the left TM. The manubrium of the malleus is also visible through the TM for both ears. A small accumulation of cerumen is visible on the inferior edge of the canal wall of the left ear. Color photographs of healthy and unhealthy TMs can be found on the text's Companion Website. (Photos provided courtesy of MedRx, Inc.)

If an imaginary line is drawn through the tympanic membrane at a 180-degree angle to the handle of the malleus and that line is bisected through the center of the tympanic membrane at right angles, the two intersecting imaginary lines thus drawn conveniently divide the tympanic membrane into four quadrants: anterior-superior, posterior-superior, anterior-inferior, and posterior-inferior. Photographs of normal right and left tympanic membranes can be seen in Figure 9.4.

The tip of the handle of the malleus is so poised as to cause the center of the tympanic membrane to be pulled inward, resulting in its concave configuration. The point of greatest retraction is called the **umbo**. To observe the tympanic membrane, it is necessary to direct a light, as from an **otoscope** (Figures 9.5 and 9.6), into the external auditory canal.

4. The human tympanic membrane is comprised of _____ layers.



FIGURE 9.5 One of a variety of handheld otoscopes used for inspection of the outer ear, ear canal, and tympanic membrane. Many pathologies in the middle-ear cavity discussed in Chapter 9 may be evidenced by their effect on the appearance of the tympanic membrane. (Courtesy of Welch-Allyn, Inc.)

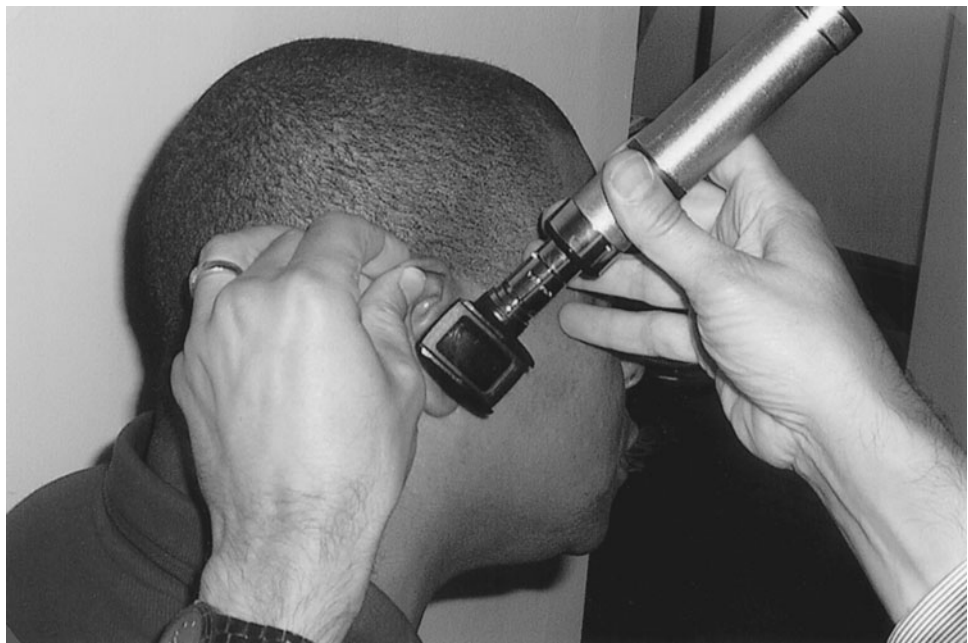


FIGURE 9.6 External inspection of the outer ear and ear canal is an important prerequisite to the hearing evaluation. Otoscopes are frequently inverted so that the otoscope handle can easily clear the patient's shoulder. The pinna is pulled upward and back (downward and back for infants) to better straighten the canal for a more direct view of the tympanic membrane, and the examiner's fingers brace the head to prevent injury to the ear canal if the patient should suddenly move. Pressing the pinna against the head while looking into the ear canal will reveal any potential for ear canal collapse during testing with supra-aural earphones.

Because the tympanic membrane is semitransparent, such a light allows some of the structures of the middle ear to become visible. However, some of the light rays directed against the membrane are reflected and refracted. The concavity of the tympanic membrane usually causes the light reflex to appear in a cone shape directed inferiorly and anteriorly.



FIGURE 9.7 A video otoscope can display the structures of the ear on a video monitor visible to both the examiner and the patient. Here a curette is used instead of the standard speculum for cerumen removal. (Courtesy of MedRx, Inc.)

One of the many modern breakthroughs in medical instrumentation is the video otoscope (Figure 9.7). It combines an otoscope with a separate light source, fiberoptic cable, video camera, and color monitor. Viewing of the tympanic membrane takes place not through the otoscope in conventional ways but by watching the video monitor, where the structures can be seen not only by the examiner but also by the patient and other interested parties. Attachments for the device allow for still photography or videotaping for later viewing.

For a demonstration of how to use a handheld otoscope and a video otoscope, see the videos titled “Otoscopic Examination” and “Video Otoscope” respectively in the Clinical Demonstrations section on the Companion Website.



The tympanic membrane is held in position at the end of the EAC by a ring of tissue called the tympanic **annulus**. The slight stretching of the tympanic membrane into the middle ear results in its tension and conical appearance. The greatest surface area of the tympanic membrane is taut and is appropriately called the pars tensa. At the top of the tympanic membrane, above the malleus, the tissues are looser because they contain only the epidermal and mucous membrane layers, resulting in the name **pars flaccida**. The pars flaccida is also called **Shrapnell's membrane**.¹

The auricle and external auditory canal provide a resonating tube through which sound waves may pass, and the tympanic membrane is the first mobile link in the chain of auditory events. Pressure waves, which impinge on the tympanic membrane, cause it to vibrate, reproducing the same spectrum of sounds that enters the external auditory canal. Movement of the tympanic membrane causes identical vibration of the malleus, to which it is attached. The further transmission of these sound waves is discussed in ensuing chapters.

Development of the Outer Ear

About 28 days after conception of the human embryo, bulges begin to appear on either side of the tissue that will develop into the head and neck. These are the **pharyngeal arches**. Although there may be as many as six arches, separated by grooves or clefts, significant information is available only about the first three: the mandibular arch, the hyoid arch, and the glossopharyngeal arch. These arches are known to have three layers, the **ectoderm**, or outer layer; the **entoderm**, or inner surface; and the **mesoderm**, or inner core. Each arch contains four components: an artery, muscle and cartilage that come from the mesoderm, and a nerve that forms from the ectoderm.

The auricle develops from the first two pharyngeal arches. The tragus forms from the first arch, and the helix and antitragus from the second arch. Development of the auricle begins before the second fetal month.

The external auditory canal forms from the first pharyngeal groove and is very shallow until after birth. A primitive meatus forms in about the 4th gestational week, and a solid core forms near the tympanic membrane in the 8th week. The solid core canalizes (forms a tube or canal) by the 28th gestational week, although the entire osseous meatus is not complete until about the time of puberty. Pneumatization of the temporal bone surrounding the external auditory canal begins in the 35th fetal week, accelerates at the time of birth, and is not complete until puberty.

The tympanic membrane annulus forms in the third fetal month. The outer layer of the membrane itself forms from ectoderm; the inner layer, from entoderm; and the middle layer, from **mesenchyme**, which is a network of embryonic tissue that later forms the connective tissues of the body, as well as the blood vessels and the lymphatic vessels. The tympanic membrane has begun formation by the beginning of the second embryonic month.

Hearing Loss and the Outer Ear

When conditions occur that interfere with or block the normal sound vibrations transmitted through the outer ear, conductive hearing loss results. Except in rare cases, the loss of hearing is rarely severe and never exceeds a 60 dB air-bone gap, because beyond that intensity, supra-aural earphones vibrate the skull and generate bone-conduction signals. Because some of the disorders alter the normal resonance frequency of the outer ear, or otherwise interfere with the osseotympanic mode of bone conduction, the bone-conduction audiogram may be slightly altered; however, this does not, in itself, suggest abnormality of the sensory/neural system.

Disorders of the Outer Ear and Their Treatments

Some abnormalities of the external ear do not result in hearing loss. They are mentioned, nonetheless, because of the audiologist's usual curiosity about disorders of the ear in general, and because abnormalities in one part of the body, specifically congenital ones, are frequently related to other abnormalities.

Disorders of the Auricle

Since hearing tests performed with earphones ignore the auricle, they do not reveal any effects it may have on hearing sensitivity, word recognition, and localization. For example, people who have had a portion or an entire auricle removed by accident or surgery, as in the case of cancer, appear to have no apparent hearing loss. At times, one or both ears may be of very small size (**microtia**), or the pinna may be very prominent and stand away from the head or be entirely absent (**anotia**). Congenital malformations of the auricle have also been associated with other disorders, such as **Down syndrome**.²

When the auricle protrudes markedly from the head, or when it is pressed tightly against the skull, a simple surgical procedure called otoplasty or pinnaplasty may be performed. These operations may improve the patient's appearance, which often has a beneficial psychological effect. In cases of missing auricles in children, plastic surgery is often inadvisable because the scar tissue formed from the grafts does not grow as does normal tissue. Plastic auricles can be made that are affixed to the head with adhesive and are amazingly realistic. Hairstyles can be arranged to conceal malformed auricles entirely.

Atresia of the External Auditory Canal

In some patients, the cartilaginous portion, the bony portion, or the entirety of the external auditory canal has never formed at all. Such congenital abnormalities may occur in one or both ears. This lack of canalization is called *otic atresia* and can occur in the EAC either in isolation or in combination with other anomalies. One inherited condition, Treacher Collins syndrome, involves the facial bones, especially the cheek and lower jaw; the auricle; and congenital atresia of the EAC.

At times, patients with Treacher Collins syndrome present with preauricular tags, which represent incomplete embryological development and appear just in front of the auricle. These do not, in themselves, cause hearing difficulties. Sometimes these tags contain a core of cartilage and are large enough to be called accessory auricles. A number of abnormalities of the middle ear and temporal bone are seen with Treacher Collins syndrome, making surgical correction quite difficult.

5. While _____ refers to an underdeveloped or very small pinna, _____ refers to an absent or closed ear canal.

The **CHARGE syndrome** is often first noticed in children because of the obvious anomalies of the pinna and external auditory canal. However, this condition can affect virtually any part of the auditory system. This acronym stands for Coloboma (a keyhole slot in the retina, iris, or optic nerve), Heart disorders, Atresia choanae (blockage of the respiratory passages), Retarded growth and development, genitourinary abnormalities, and Ear anomalies. CHARGE is a genetic disorder that occurs in one out of every 10,000 to 15,000 births (Thelin & Swanson, 2006) and, because of the multiple disorders, presents major difficulties in habilitation to audiologists, speech-language pathologists, and physicians.

Not all closures of the external auditory canal are congenital; some may occur as the result of trauma or burns. Trauma to the outer ear may result in an unsightly blood blister, called a hematoma. Since the pinna protrudes from the side of the head, it can be damaged by sunlight or extreme cold. Frostbite can appear rather like a severe burn. Either condition can lead to loss of the pinna.

Sometimes when an ear is malformed in a small child, it is difficult to determine whether the condition is one of congenital atresia or a marked stenosis (narrowing) of the canal. Surgical procedures for correction of atresia of the EAC have improved in recent years, and surgeons have been assisted greatly by the advent of modern imaging techniques. Chances for success are better when only the cartilaginous canal is involved, and when the middle ear and

tympanic membrane are normal. Drillouts of the bony canal have led to some serious after-care problems. Although in some cases it may appear that it is better to treat a child with a congenital external-ear-canal atresia with a hearing aid rather than with surgery, the ultimate decision on such matters is always left to the family in consultation with a physician.

Stenotic EACs do not produce hearing loss, as does atresia, although earwax or other debris can easily clog the very narrow lumen and thus cause a conductive problem. In cases of atresia of the canal, the hearing loss is directly related to the area and the amount of occlusion. The loss may be mild if only the cartilaginous area is involved, and certainly will be more severe if the bony canal is occluded. As stated earlier, a congenital anomaly in one part of the body increases the likelihood of another anomaly elsewhere. For this reason, when an atresia is seen, it must be suspected that the tympanic membrane and middle ear may likewise be involved. Figure 9.8 shows the test results for a theoretical patient with atresia of both

external ear canals. Notice that the conductive loss reaches near maximum (about 60 dB). In cases of atresia, the valuable information from measurements of acoustic immittance and oto-acoustic emissions is unobtainable because the probes cannot be inserted into the EAC.

6. Hearing losses in the outer ear are caused by _____.

Collapsing External Auditory Canals

7. Ear canal collapse during pure-tone audiometry can lead to erroneous results. This collapse can be avoided through the use of _____.

At times a conductive hearing loss appears during examination because the pressure of a supra-aural earphone causes the auricle to move forward, blocking the opening of the canal, and attenuating sound entering it. Often the patient does not experience the loss subjectively. Inspection of the ear prior to testing can often prevent the finding of a false conductive hearing loss. When insert earphones, which circumvent the problem of earphone-induced canal collapse, cannot be used, a plastic tube can be inserted into the canal with a strong string attached for easy retrieval, or a wedge of foam rubber can be put behind the pinna before the headset is placed in position.

Collapsing external ear canals may occur in as many as 4% of a typical audiology caseload, with most incidences occurring at the extremes of the age spectrum. Among children, collapse is possible because the outer portion of the ear canal is less rigid before 7 years of age. Among the elderly, the greater elliptical shape of the canal coupled with the more flaccid nature of the cartilaginous outer portion of the canal can lead to collapse. The otoscopic examination should include inspection for canal collapse that may be induced by the pressure of supra-aural earphone cushions. The problems of collapsing ear canals during audiometric testing are completely circumvented with insert earphones.

Foreign Bodies in the External Ear Canal

8. While it is in the audiologist's scope of practice to remove obstructions from the outer ear canal, when complications arise, this procedure is best performed by _____.

For unexplained reasons, children, and sometimes adults, place foreign objects, such as paper, pins, and crayons, into their mouths, noses, and ears. If the object is pushed past the osseocartilaginous junction of the external ear canal, swelling at the isthmus formed by this junction may result. Although hearing loss may result from such an incident, it is of secondary importance to prompt and careful removal of the object, which may be a formidable task and may require surgery in some cases.

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AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☐ Supra Aural ☒	RIGHT									LEFT								
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000
Masking Type	55	60	60	60	55	60	65	65	70	60	55	55	60	60	60	65	65	60
NB ☒	55	60	60	60	55	60	65	65	70	60	55	55	60	60	60	65	65	60
EM Level in Opp. Ear	60	55	55	60	60	60	65	65	60	55	60	60	60	55	60	65	65	70

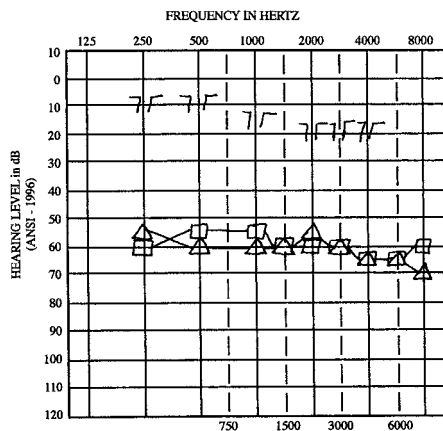
BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT						FOREHEAD						LEFT					
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type WB ☐ NB ☒	10	10	15	20	20	20	10	10	15	20	20	20	10	10	15	20	20	20
EM Level in Opp. Ear	60	55	55	60	60	65							55	60	60	55	60	65

Pure Tone Average	2 Freq	3 Freq	Variable	WEBER						Pure Tone Average	2 Freq	3 Freq	Variable
58	58	62		M	M	M	M	M	M	55	57	60	

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☒	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
	60	60	List 100% HL	List HL %	60	60	List 96% HL	List HL %
EM Level in Opp. Ear		60	95			60	100	



Speech Presentation

MLV Recorded ☐

SRT ☒

WRS ☐

COMMENTS

AUDIOGRAM KEY

Right	Left
AC Unmasked	○
AC Masked	×
BC Mastoid Unmasked	<
BC Mastoid Masked	>
BC Forehead Unmasked	[
BC Forehead Masked	]

Both

BC Forehead Unmasked	∇
Sound Field (unaided)	S
Sound Field (aided)	•
Opp Ear Masked	*

Examples of No Response Symbols

○	×
∇	]

FIGURE 9.8 Audiogram showing a moderately severe conductive hearing loss in both ears consistent with Treacher Collins syndrome. Since both external ear canals are atretic, insert earphones cannot be used and the supra-aural receivers are placed where the external auditory canals would normally be found. Note the large air-bone gaps with essentially normal bone conduction. The SRTs and pure-tone averages are in close agreement, and the word-recognition scores are normal.

External Otitis

An infection that occurs in the skin of the external auditory canal is called **external otitis**. The condition is often referred to as “swimmer’s ear,” because it frequently develops in people who have had water trapped in their ears. External otitis is quite common in tropical areas. External ear infections are often called “fungus,” although bacterial infections are more common. **Otomycosis**, or fungal external-ear infection, is rare and may be caused by the overuse of eardrops.

External otitis may originate from allergic reactions to earplugs, hearing-aid earmolds, soap, or other allergens. **Furunculosis**, infection of hair follicles, may begin with infection of a single hair in the lateral third of the external auditory canal and spread to involve the entire area.

Systemic antibiotics or eardrops are frequently unsuccessful in the treatment of external otitis, because the pocket of infection may be accessible neither topically nor through the bloodstream. Itching is a common complaint in early or mild infections. Patients with more advanced infections are sometimes in extreme pain, especially upon touch to the infected area, which may become red and swollen and may produce a discharge. Often body temperature elevates. The condition may be successfully treated by irrigating the canal with warm saltwater, drying it carefully, and applying topical antibiotics. Sometimes a cotton wick saturated with antibiotic drops is inserted into the canal. The skin may be treated topically with steroids to curtail the inflammation.

9. True/False
Systemic antibiotics are usually the most effective treatment for external otitis.

Hearing tests often cannot be performed on patients with external otitis because the ear is too painful to allow the pressure of supra-aural earphones or the penetration of insert earphones. It is suspected that if the lumen of the canal is closed, either by the accumulation of infectious debris or by the swelling of the canal walls, a mild conductive loss is likely, as shown in Figures 9.9 and 9.10. Some concern has been expressed by audiologists regarding the contamination by bacteria of supra-aural earphones and their rubber cushions. Large colonies of certain organisms may be found on earphone cushions (Kemp, Roeser, Pearson, & Ballachanda, 1995). These can often be controlled using ultraviolet light.

Sometimes the tympanic membrane itself becomes inflamed, often in response to systemic viral infection. The patient may develop blood blisters on the surface of the tympanic membrane, which in turn produce fever and pain. Often these blebs must be carefully lanced to relieve the pain. Inflammations of the tympanic membrane are called **myringitis**.

Several forms of external otitis are considered particularly dangerous to the patient and require rather aggressive therapy. For example, necrotizing, or malignant, external otitis is often initially a routine infection of the skin of the external auditory canal. The condition is particularly threatening to diabetic and elderly patients and may result in massive bone destruction in the external, middle, and inner ears. It can also result in **osteitis** and in **osteomyelitis** of the temporal bone. Patients suffering from this condition, which is often fatal, may be hospitalized and treated with systemic antibiotics. Surgery is sometimes required to stop the spread of infection through the bone.

Growths in the External Auditory Canal

Tumors, both benign and malignant, have been found in the EAC. Bony tumors, called osteomas, do not present hearing problems unless their size is such that the lumen of the canal is occluded and conductive hearing loss results; however, they may result in serious infection of the EAC. Some physicians believe that osteomas should be removed and biopsied to be certain they are not malignant.

Exostoses, the outward projections for the surfaces of bone, are sometimes seen in the ears of people who have done a great deal of swimming in cold water. To the untrained eye, such protrusions in the bony wall of the EAC may be confused with osteomas. As with osteomas, exostoses require treatment only when their size produces a conductive hearing loss or when they block the normal cleansing action of the EAC, resulting in infection.

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AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐	RIGHT										LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000		
Masking Type WB ☐ NB ☐	0	0	0	0	5	10	5	10	10	20	25	25	25	30	25	30	30	35		
EM Level in Opp. Ear																				

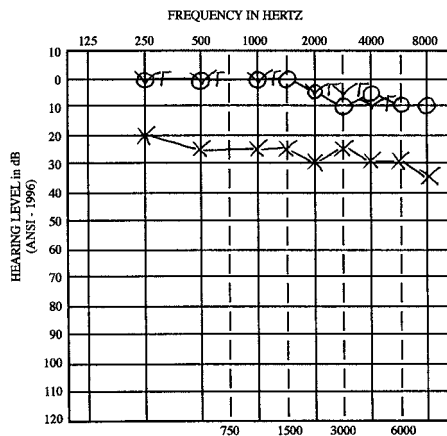
BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT						FOREHEAD						LEFT					
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type WB ☐ NB ☒							0	0	0	5	5	10	0*	0*	0*	5*	5*	10*
EM Level in Opp. Ear													20	10	5	5	10	5

	2 Freq	3 Freq	Variable	WEBER						2 Freq	3 Freq	Variable	
Pure Tone Average	0	2	3	L	L	L	L	L	L	Pure Tone Average	25	27	28

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☒	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
	5		List 35% HL 100%	List 35% HL 98*	30		List 2% OHL 100%	List 2% OHL 100*
EM Level in Opp. Ear				45				20



Speech Presentation

MLV Recorded ☒

SRT ☒

WRS ☒

COMMENTS

AUDIOMETER KEY

Right	Left
AC Unmasked	○
AC Masked	△
BC Mastoid Unmasked	<
BC Mastoid Masked	>
BC Forehead Unmasked	□
BC Forehead Masked	◇

Both

BC Forehead Unmasked	▽
Sound Field (unaided)	S
Sound Field (aided)	•
Opp Ear Masked	*

Examples of No Response Symbols

○	×
△	◇

FIGURE 9.9 A mild unilateral (left) conductive hearing loss, due to external otitis. SRT and pure-tone findings are in close agreement, and word-recognition scores are normal. Masking is needed for the left ear for bone conduction and higher-level WRS. The Weber results show lateralization to the left ear.

Color photographs of exostoses and osteomas, as well as a variety of additional pathological conditions of the outer ear, including frostbite, cholesteatoma, microtia with atresia, mucoid otitis media, cerumen occlusion, and others, may be found under Ear Pathology on the Companion Website.



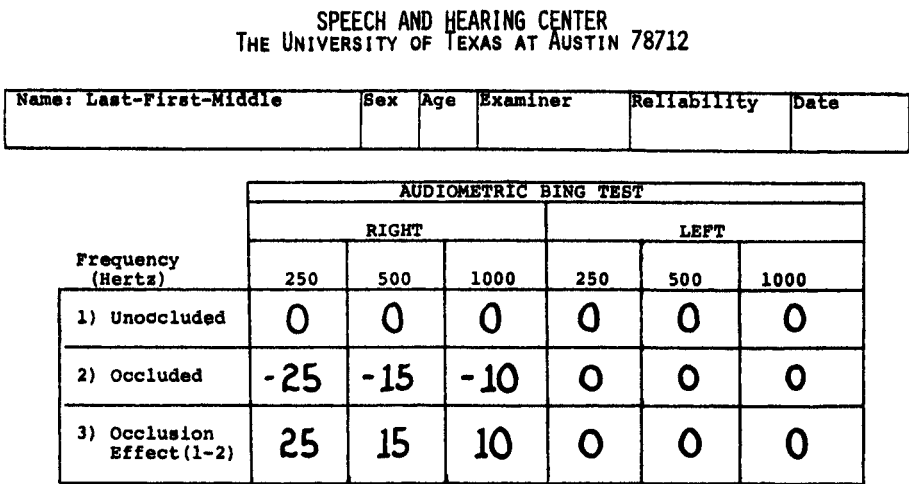


FIGURE 9.10 Results on the audiometric Bing test for a patient with unilateral conductive hearing loss caused by external otitis (see Figure 9.7). Note the absence of the occlusion effect in the left ear on the Bing test.

Earwax in the External Auditory Canal

In some cases the wax glands in the EACs are extremely active, producing copious amounts of cerumen. When the canal is small, it may become blocked and cause a hearing loss. Even when a large amount of wax is found in the ear, hearing may remain normal as long as there is a tiny opening between the tympanic membrane and the outside environment. Overzealous cleaning of the external ears, however, may result in cerumen being pushed from the cartilaginous canal into the bony canal, where natural cleansing cannot take place. Cotton swabs and wadded tissues are often used for such purposes, frequently by well-meaning parents on the ears of their children. As people age, the cartilage in the EAC begins to lose its support, narrowing the canal and thereby causing more problems with wax accumulation. This can be particularly annoying when water is trapped behind the wax.

Once the cerumen is deposited in the bony canal, it remains there until it is properly removed. Wax deposited in the bony canal becomes dry, causing itching, which encourages the individual to push still more wax from the cartilaginous canal by instruments such as cotton swabs. Sometimes water pressure during diving forces wax deep into the canal. As in the case of external otitis, the amount of hearing loss produced by impacted cerumen is directly related to the amount of ear canal occlusion, with hearing losses ranging from very mild to moderate.

Because more and more audiological procedures—such as testing with insert receivers, immittance measures, electrocochleography, and the fitting of hearing aids—require patients’ external ear canals to be clear, the role of the audiologist has changed concerning cerumen removal. The removal of cerumen by audiologists specifically trained in this procedure is included in the scopes of audiological practice of both the American Academy of Audiology and the American Speech-Language-Hearing Association.

Prior to cerumen removal, a complete history must be taken to rule out possible tympanic membrane perforation, ear disease, or the presence of **pressure-equalizing tubes** (see Chapter 10). If anything in the history seems to contraindicate the audiologist’s removal of the cerumen (e.g., diabetes, AIDS, previous ear surgery), the patient should be referred to a physician to have the wax removed.

10. The degree of hearing loss produced by cerumen accumulation is related to the amount of ear canal _____ and may range from _____ to _____.

Careful otoscopic examination must be performed, in part, to determine that it is cerumen and not some other substance or object occluding the canal. If the tympanic membrane can be seen, its integrity should be ascertained, which is often most efficiently done using tympanometry. In many older patients the cartilaginous external auditory canal loses its firmness and partially collapses, narrowing the canal and making earwax removal more difficult.

To facilitate cerumen removal, an approved **cerumenolytic**, a chemical substance known to safely soften earwax, may be used. This substance should be placed into the ear at least an hour before removal is attempted; however, it is preferable for patients to use the substance several times a day for several days prior to cerumen removal. The harder and dryer the cerumen is found to be at examination, the longer the wax will take to soften, but when soft, the wax can often be simply suctioned out of the ear.

Although many audiologists use water irrigation to flush the cerumen from the external auditory canal, many others prefer the use of suction and curesttes for mechanical removal. Of course, proper illumination is essential, as from a headlamp or, preferably, a surgical microscope or video otoscope. Audiologists must be careful whenever they insert any object or perform any procedure on a patient's external ear, and all procedures should be duly noted in the patient's chart.

An ancient technique purported to be effective for cerumen removal, which may go back nearly 5,000 years, is called "ear candling." For this maneuver a special hollow candle, usually 10 to 12 inches in length, is placed into the concha, and the opposite end is lighted. The purpose is to create a partial vacuum to remove earwax. Claims that the use of ear candles not only rid the ear of wax but also provide a wide range of "cures" to human maladies are unsupported, and while there is no scientific evidence that there is any medical efficacy in this procedure (Shenk & Dancer, 2004), it remains extremely popular, most especially in third-world countries. In the United States many thousands of these candles are sold annually, and they are frequently found in health-food stores. A variation of this procedure has been carried out by forming a sheet of paper into a cone, placing the narrow end into the external ear and lighting the more open end. There are no available data to support the use of ear candling, and it is obviously not free of the risk of mild-to-severe burns.

Perforations of the Tympanic Membrane

The tympanic membrane may become perforated in several ways. Excessive pressure buildup during a middle-ear disorder may cause rupturing of the membrane. Sometimes, in response to infection, usually in the middle ear, the membrane may become necrosed (dead) and perforate.

A frequent cause of perforation is direct trauma from a pointed object such as a cotton swab or hairpin. This may happen if patients are attempting to cleanse their own ears and either misjudge the length of the EAC or are jarred or startled while probing in it. Such accidents are extremely painful, as well as embarrassing. The tympanic membrane may also be perforated from sudden pressure in the external ear canal, as created by a hand clapped over the ear or an explosion. The amount of hearing loss produced by a perforated tympanic membrane depends on several variables. The exact size and place of the perforation can cause variations not only in the amount of hearing loss but in the audiometric configuration as well.

Because traumatic perforations alter what is essentially normal tissue, they tend to show spontaneous closure better than do perforations resulting from disease. Perforations in the inferior portion of the tympanic membrane heal more rapidly than those in the superior portion, because the normal epithelium migration is more active inferiorly. Placing a thin piece of

cigarette paper over the perforation has encouraged the migration of tissue. Often, when a perforation is thus healed, the mucosal and epidermal layers close off the opening but a thin area remains in the fibrous layer, which does not migrate as well. Such thin areas in the tympanic membrane lend themselves to easy reperforation, as from water irrigation of the external canal or even a strong sneeze.

11. Surgical repair of the tympanic membrane is called _____.

Surgical repair of a perforated tympanic membrane is called **myringoplasty**. In early versions of myringoplasty, skin grafts, usually taken from the inner aspect of the arm, were placed over the perforation. Even though the grafts often “took” initially, they tended to desquamate (flake off), with consequent reperforation. Vein grafts, taken from the patient’s hand or arm, later replaced skin grafts. Vein works well for this purpose because its elasticity is similar to that of the fibrous layer of the tympanic membrane; however, narrow veins are inadequate for large perforations. Most middle-ear surgeons today prefer to use fascia, the tough fibrous protective covering over muscle. Results with myringoplasty have been very gratifying.

Measurements on acoustic immittance meters are sometimes impossible because an airtight seal cannot be formed as a consequence of pressure leakage from the air pump of the meter through the perforation into the middle ear. The immittance meter can detect perforations that may not be readily visible with the naked eye because of their small size. If a seal can be obtained when there is a tympanic membrane perforation, the c_1 value will be very large, because the air in the outer-ear cavity is continuous with the air in the middle-ear cavity.

Thickening of the Tympanic Membrane. Often, in response to infection, usually of the middle ear, the tympanic membrane becomes thickened and scarred. At times calcium plaques appear, adding to the mass of the tympanic membrane and interfering with its vibration but sometimes causing no appreciable hearing loss. Such conditions are called **tympanosclerosis**, and they do not respond well to medical or surgical treatment.

Often the tympanic membrane can become quite thickened. The thickening can be coincidental with disorders of the middle ear, thus making it impossible to determine the amount of hearing loss each disorder contributes.



A variety of external-ear-canal maladies including outer-ear microtia, canal stenosis, osteomas and exostoses of the ear canal, impacted cerumen, and external otitis can be seen on the Companion Website under Ear Pathology Slides.

Summary

The outer ear, including the auricle, external auditory canal, and tympanic membrane, is the channel by which sounds from the environment are first introduced to the hearing mechanism. The auricle helps gather the sound, the external auditory canal directs it, and the tympanic membrane vibrates in sympathy with the airborne vibrations that strike it. When portions of the

outer ear are abnormal or diseased, hearing may or may not become impaired, depending on which structures are involved and the nature of their involvement.

Abnormalities of the external ear do not affect the sensory/neural mechanism. However, alterations in the canal may cause a change in the osseotympanic mode of bone conduction, which may alter the bone-conduction curve slightly. Audiometric findings on word recognition and site-of-lesion tests are the same as expected for persons with normal hearing. Measurements on the acoustic immittance meter are frequently impossible in external-ear anomalies, by virtue of the disorders themselves.

Whenever an audiologist sees a patient with an external-ear disorder, an otological consultation should be recommended. If hearing is impaired and no medical therapy is available, audiological treatment options should be investigated, depending on the extent of hearing loss and the needs of the patient.

REVIEW TABLE 9.1 The Outer Ear

<i>Anatomical Area</i>	<i>Disorder</i>	<i>Causes Hearing Loss</i>	<i>Treatment</i>
Auricle	Missing, small, or malformed	No	Plastic surgery
External auditory canal	Wax	Sometimes	Removal
	Infection	Sometimes	Medical treatment
	Atresia	Yes	Surgery
	Stenosis	Sometimes	Observation/surgery
Tympanic membrane	Foreign bodies	Sometimes	Removal
	Perforation	Yes	Surgery
	Thickening	Sometimes	Sometimes

Study Questions

1. Make sketches of the outer ear and tympanic membrane. Label from memory as many parts as you can. Compare your drawings with the ones in Figures 9.1, 9.2, and 9.3.
2. List as many disorders of the outer ear as you can remember. Divide them into two columns, those that produce hearing loss and those that do not.
3. For each of the disorders you listed that produce hearing loss, draw a pure-tone audiogram. Predict the probable SRT, word-recognition scores, and results on the tuning-fork tests discussed earlier.

Suggested Readings

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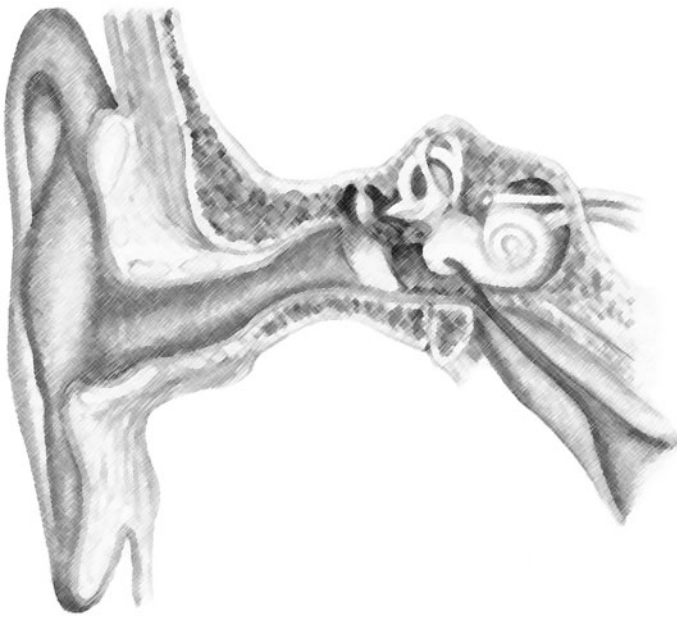
Endnotes

1. For Henry Jones Shrapnell, nineteenth-century British anatomist.
2. Named for John Langdon Haydon Down, British physician, 1828–1896.

References

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CHAPTER 10



The Middle Ear

THIS CHAPTER ASSUMES a basic understanding of hearing loss as introduced in Chapter 2, the physics of sound in Chapter 3, and the details of hearing tests and their interpretation in Chapters 4 through 7. Oversimplifications of the anatomy of the middle ear and its function, provided as an introduction earlier in this book, should be clarified. The development of the middle ear was no doubt one of evolution's most splendid engineering feats. The middle ear carries vibrations from the outer ear to the inner ear by transferring the sound energy from the air in the outer ear to the fluids of the inner ear. The middle ear overcomes the loss of energy that results when sound passes from one medium (in this case, air) to another medium (fluid).

LEARNING OBJECTIVES

- At the completion of this chapter, readers should be able to
- Describe the anatomy and physiology of the middle ear.
 - Recognize some of the etiologies and treatments of common disorders that produce conductive hearing loss.
 - Predict the typical audiometric results for middle-ear pathologies discussed in this chapter.
 - Make a reasonable attempt at stating the etiology of a conductive hearing loss based on audiometric and other findings.

Anatomy and Physiology of the Middle Ear

An average adult middle ear is an almost oval, air-filled space of roughly 2 cm³ (about one-half inch high, one-half inch wide, and one-quarter inch deep). The roof of the middle ear is a thin layer of bone, separating the middle-ear cavity from the brain. Below the floor of the middle ear is the **jugular bulb**, and behind the anterior wall is the **carotid artery**. The labyrinth of the inner ear lies behind the medial wall, and the **mastoid process** is beyond the posterior wall. The lateral portion of the middle ear is sometimes called the membranous wall, as it contains the tympanic membrane. The space in the middle ear above the tympanic membrane is called the **epitympanic recess**.

As is shown in Figure 10.1, the middle ear is separated from the external auditory canal by the tympanic membrane. The middle ear is connected to the **nasopharynx**, that area where the back of the throat and the nose communicate, via the **eustachian tube**. The eustachian tube and middle ear form the **middle-ear cleft**. The entire middle-ear cleft, including the surface of the tympanic membrane that is within the middle ear, is lined with **mucous membrane**, the same lining found in the nose and paranasal sinuses. Much of this mucous membrane is ciliated; that is, the topmost cells contain **cilia**, small hairlike projections that provide a motion similar to that of a wheat field in the wind. The motion of the cilia creates a wiping action that helps to cleanse the middle ear by moving particles down and out of the eustachian tube.

The Eustachian Tube

The eustachian tube¹ enters the middle ear anteriorly at a 30 degree angle and passes down into the nasopharynx for a distance of about 36 millimeters. The tube is lined with ciliated epithelium, and the underlying tissue is bone in the superior one-third and cartilage in the inferior two-thirds. In adults the tube is normally kept closed by the spring mechanism of cartilage and is opened by the action of three sets of muscles at the orifice of the tube in the nasopharynx. This opening occurs during yawning, sneezing, or swallowing, or when excessive air pressure is

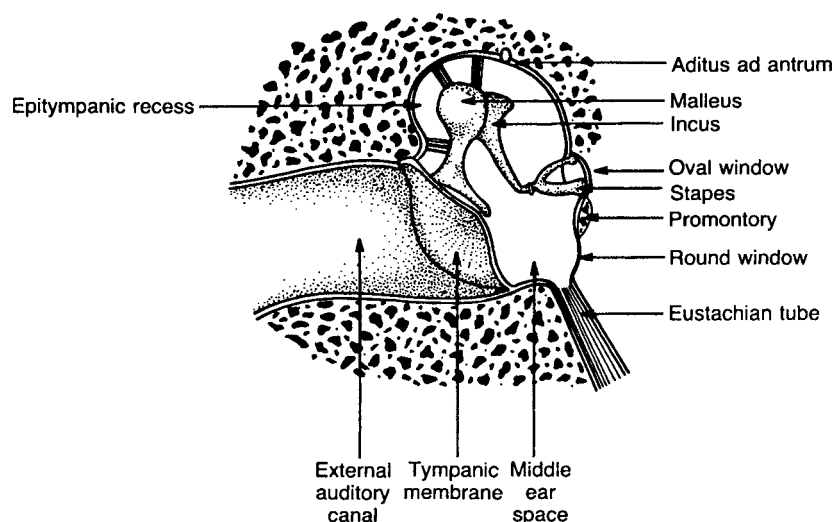


FIGURE 10.1 The human middle ear in cross section.

applied from the nose. While we are awake, our eustachian tubes open about once per minute; during sleep, on an average of once every five minutes. In infants the eustachian tube is shorter and wider in relation to its length and in a more horizontal plane than it is in adults. The orifice of the eustachian tube in the nasopharynx tends to remain open in infants until the age of about 6 months.

The air pressure of the middle ear must match that of the external auditory canal to keep the pressure equal on both sides of the tympanic membrane to maximize its mobility. The absorption of air by middle-ear tissues is the major reason for the need for a pressure-equalization system. The only way for this pressure equalization to be maintained is through the eustachian tube. At one time or another most people have had the experience of fullness in the ear—for example, when flying or driving to a higher or lower elevation. During ascension, this fullness results when the air in the external ear canal becomes rarefied (thin), while the middle ear remains at ground-level pressure. The sense of fullness occurs when the tympanic membrane is pushed outward by the greater pressure from within the middle ear. Upon descent, the pressure in the middle ear may be less than in the external ear canal, so that the tympanic membrane is pushed in. The sensations are the same whether the tympanic membrane is pushed in or out. The simple solution is to swallow, yawn, or otherwise open the eustachian tube so that the pressure may be equalized. Because the normal function of the tube is to replenish air pressure, moving from lesser to greater air pressure is more traumatic. At extreme pressures the eustachian tube will lock shut, making pressure-equalization impossible, and great pain and tympanic-membrane rupture likely. A new type of earplug has been developed for people who experience eustachian-tube difficulties during flying. The plugs are flanged and gradually release pressure during ascent and descent, providing decreased discomfort for many flyers.

1. The purpose of the eustachian tube is to match the pressure of the middle ear to the pressure of the _____.

Clinical Commentary

Air-pressure differentials between the ambient pressure and that within the middle ear created during air travel can be quite painful for some passengers. The following clinical advice is often given by physicians and may prove helpful to these persons:

1. Take an over-the-counter decongestant one hour prior to takeoff.
2. One-half hour prior to takeoff, spray the nose with a nasal decongestant.
3. One-half hour prior to landing, repeat number 2.
4. Chew gum and pop the ears, particularly while landing.

The Mastoid

Figure 10.1 shows that some of the bones of the skull that surround the ear are not solid but rather are honeycombed with hundreds of air cells. Each of these cells is lined with mucous membrane, which, though nonciliated, is similar to that of the middle-ear cleft. These cells form the **pneumatic mastoid** of the temporal bone. The middle ear opens up, back, and outward in an area called the **aditus ad antrum** to communicate with the mastoid. The bony protuberance behind the auricle is called the mastoid process.

Windows of the Middle Ear

A section of the bony portion of the inner ear extends into the middle-ear space. This is caused by the basal turn of the cochlea, which is described in Chapter 11. This protrusion is the **promontory** and separates two connections between the middle and inner ear. Above the promontory is the **oval window** and below it the **round window**, both of whose names are derived from their shapes. The round window is covered by a very thin, but tough and elastic, membrane. The oval window is filled by a membrane that supports the base of the stapes, the tiniest bone of the human body.

Bones in the Middle Ear

2. The three middle-ear ossicles are the _____, _____, and _____.

To accomplish its intended function of carrying sound waves from the air-filled external auditory canal to the fluid-filled inner ear, the middle ear contains a set of three very small bones called **ossicles**. Each of these bones bears a Latin name descriptive of its shape: **malleus**, **incus**, and **stapes** (the mallet, anvil, and stirrup).

The **manubrium** (handle) of the malleus is embedded in the middle (fibrous) layer of the tympanic membrane; it extends from the upper portion of the tympanic membrane to its approximate center (the umbo). The head of the malleus is connected to the body of the incus, and this area of connection extends upward into the aditus ad antrum (or epitympanic recess). Details of the anatomy of the malleus are shown in Figure 10.2. The incus (Figure 10.3) has a long process, or **crus**, which turns abruptly to a very short crus, the lenticular process. The end of the lenticular process sits squarely on the head of the stapes. As is shown in Figure 10.4, the stapes comprises a head, neck, and two **crura** (plural of crus). The posterior crus is longer and thinner than the anterior crus to aid in its rocking motion. The base, or **footplate**, of the stapes occupies the space in the oval window.



Additional schematic illustrations of the middle-ear ossicles and their ligaments may be found under “Anatomy” in the Learning Supplements section of the Companion Website.

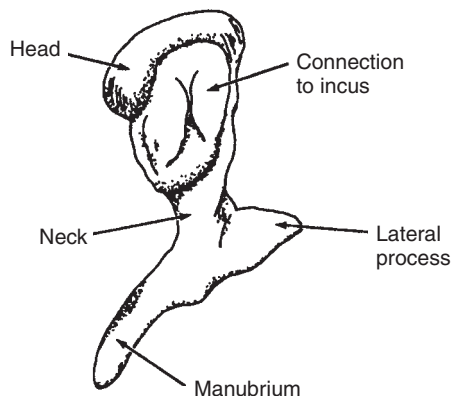


FIGURE 10.2 Anatomy of the human malleus.

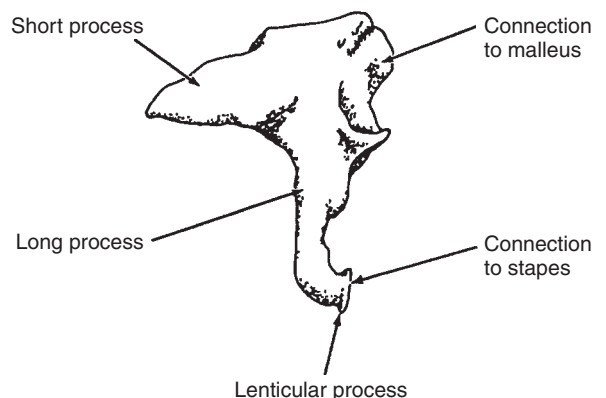


FIGURE 10.3 Anatomy of the human incus.

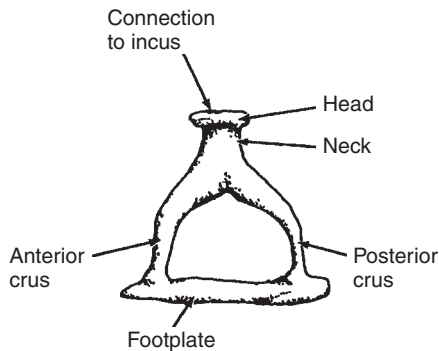


FIGURE 10.4 Anatomy of the human stapes.

Because the malleus and incus are connected rather rigidly, inward and outward movement of the umbo of the tympanic membrane causes these two bones to rotate, thus transferring this force to the stapes, which in turn results in the inward and outward motion of the oval window. Each of the ossicles is so delicately poised by its ligamental connections within the middle ear that the collective function is unaltered by gravity when the head changes in position. The photograph in Figure 10.5 illustrates the very small size of the ossicles.

Vibrations of the tympanic membrane are conducted along the ossicular chain to the oval window. The chain (2 to 6 mm in length) acts much like a single unit when transmitting sounds above about 800 Hz. It is the action of these ossicles that provides the energy transformation for which the middle ear is designed.

3. Vibratory connections between the ossicular chain and the inner ear are established by the _____.

The Middle-Ear Impedance Matcher

Fish have an organ called the lateral line that is similar in some ways to an unrolled version of the cochlea of the inner ear of humans. As its name implies, this fluid-containing structure runs along the sides of the fish's body. The water in which the fish swims conducts waves that distort the membranes covering the lateral lines, setting the fluids within them into motion. This leads



FIGURE 10.5 Three human ossicles shown against a penny to illustrate their small size.

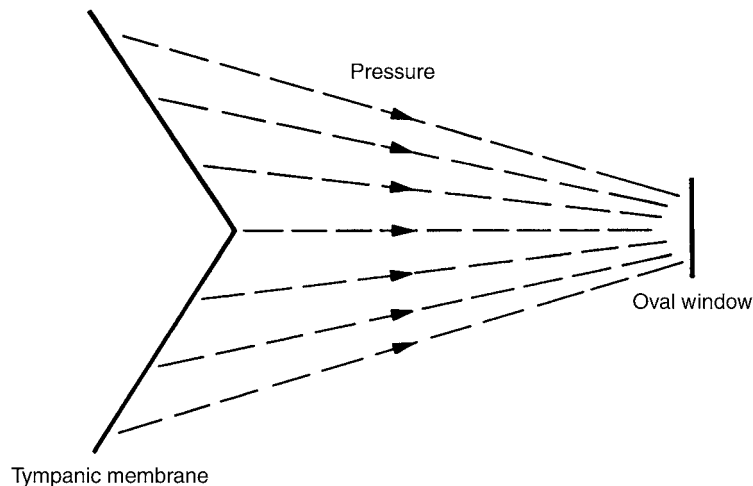


FIGURE 10.6 Sound pressure collected over the surface area of the tympanic membrane is concentrated on the (smaller) surface area of the oval window, thus increasing the pressure.

to perception in the fish's brain, the nature of which is not understood. Fish have no need for an impedance matcher.

The average adult tympanic membrane is 85 to 90 mm², but the effective vibrating area is only about 55 mm². This vibrating area is 17 times that of the oval window. Therefore, the sound pressure collected over the larger area of the tympanic membrane is concentrated on the oval window, which increases the sound pressure in the same way that a hose increases water pressure when a thumb or a finger is placed over the opening. What results is not a greater volume of water but greater pressure. The drawing in Figure 10.6 illustrates this action. Despite the exquisite engineering of the middle ear, all sound pressure delivered to the tympanic membrane is not made available to the inner ear since the middle-ear mechanism is not 100% efficient as an impedance-matching device.

The mass of the ossicular chain (malleus = 25 mg, incus = 25 mg, stapes = 2.5 mg) is poised to take advantage of the physical laws of leverage. Figure 10.7 illustrates this simple principle. Through leverage, the force received at the footplate of the stapes is greater than that applied at the malleus. In this way, the ratio of tympanic membrane displacement to oval window displacement is increased by about 1.3:1. The ossicular chain actually rocks back and forth on an axis, and the action of the stapes in the oval window is not that of a piston but, rather, like a pivot.

The combined effects of increased pressure and the lever action of the malleus result in a pressure increase at the oval window 23 times what it would be if airborne sound impinged on it directly. This value is equivalent to approximately 30 dB, remarkably close to the 28 dB loss that would be caused by the air-to-fluid impedance mismatch without the ossicular chain. The fact that the tympanic membrane is conical, rather than flat, assists slightly in the process of impedance matching by increasing the force and decreasing the velocity, because the handle of the malleus does not move with the same amplitude as the tympanic membrane.

4. A main function of the middle ear is to match the impedance of the air in the external auditory canal to the impedance of the _____.

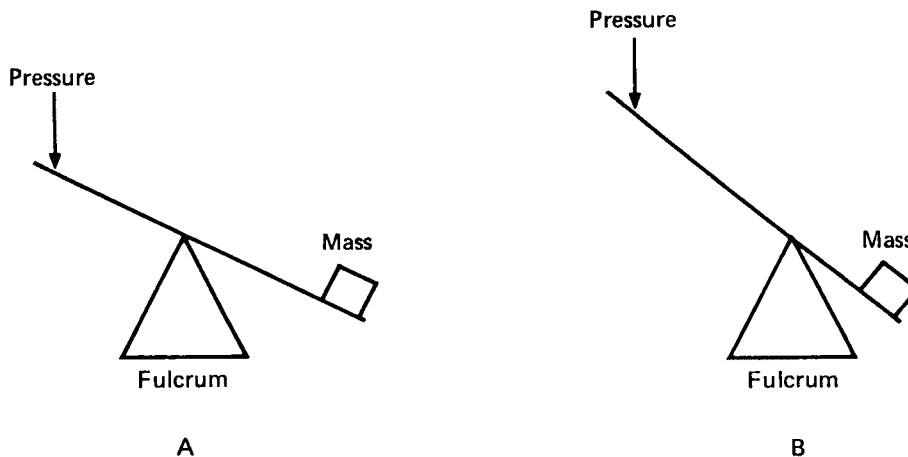


FIGURE 10.7 Demonstration of the advantage of lever action. Note that the advantage is increased in B when the fulcrum is moved closer to the mass to be lifted.

Nonauditory Structures in the Middle Ear

The middle ear contains several structures that are unrelated to hearing. The **fallopian canal**, containing a portion of the facial (VIIth cranial) nerve, passes through the middle ear as a protrusion on its medial wall. The fallopian canal is a bony channel covered with mucous membrane. The **facial nerve** runs beside the auditory (VIIIth cranial) nerve as the two travel to the brainstem, about which more is said in Chapter 12.

The **chorda tympani nerve** is a branch of the facial nerve that passes through the middle-ear space. This nerve carries information about the sensation of taste from the anterior two-thirds of one side of the tongue. Unfortunately, the chorda tympani frequently acts as an obstruction during middle-ear surgery. Sometimes the nerve is accidentally or intentionally sacrificed to increase visibility of the operative field. Taste changes caused by surgical severance of the chorda tympani nerve frequently disappear after several months.

5. The facial nerve is contained in the _____.

6. The chorda tympani nerve provides information about the sense of _____ and is a branch of the _____ cranial nerve.

The Middle-Ear Muscles

Two muscles, the primary functions of which continue to be debated, are active in each middle ear. It has been thought that contractions of these muscles may serve a protective function for the inner ear by stiffening the ossicular chain and attenuating loud, and therefore potentially damaging, sounds that enter it. It is known, however, that the latency of the reflex is too long to protect the inner ear from impulsive sounds such as gunshots. Contraction of these muscles may additionally serve to decrease the loudness of sounds generated within the head, for example, by chewing or speaking.

The **stapedius muscle** (length 7 mm, cross section 5 mm²) originates in the posterior (mastoid) wall of the middle ear. The stapedius tendon emerges through a tiny hole in the mastoid wall, but the muscle itself is in a canal beside the facial canal. The tendon attaches to the posterior portion of the neck of the stapes. When the stapedius muscle is contracted, the stapes

moves to the side and tenses the membrane in the oval window, reducing the amplitude of vibration. It is possible that contraction of the stapedius muscle may help to improve word recognition in noise by attenuating the low-frequency components of the noise. The stapedius muscle is innervated by a branch of the facial nerve. In addition to its function of attaching the stapedius muscle to the stapes, the stapedius tendon also supplies blood to the lenticular process of the incus.

7. The muscles that operate in the middle ear are the _____ and the _____.

The **tensor tympani muscle** (length 25 mm, cross section 5 mm²) is also encased in a small bony cavity. The tendon from this muscle inserts into the manubrium of the malleus and, upon contraction, moves the malleus in such a way that the tympanic membrane becomes tense. The innervation of the tensor tympani is from the **trigeminal** (Vth cranial) **nerve**.

Both the stapedius and tensor tympani muscles respond reflexively and bilaterally, but in humans only the stapedius is thought to respond to sound. For example, introduction of a loud sound into the right ear will cause both stapedius muscles to contract. The tensor tympani can be caused to contract by a jet of air in the external auditory canal or the eye and by changes in temperature or touch in the external auditory canal.

Development of the Middle Ear

During embryonic or fetal development, specific anatomical areas form, or differentiate. Like the outer ear, the middle ear and eustachian tube form from the pharyngeal arch system, limited to the first two arches. As in the outer ear and all areas of the body, developmental milestones are somewhat variant and at times should be viewed as approximate.

Both the middle-ear space and the eustachian tube form the first pharyngeal pouch, which is lined with entoderm. During gestation, the middle-ear space is filled with mesenchyme (a diffuse network of cells forming the embryonic mesoderm) as the ossicles are developing. The ciliated epithelium that lines these spaces also arises from the entoderm. The oval window is formed by about the 47th gestational day.

The ossicles first form as cartilage of the first and second pharyngeal arches. The superior portions of the incus and malleus, which form the incudomalleal joint, come from the first arch. The lower parts of the incus and malleus, and the superstructure of the stapes, come from the second arch. The base of the stapes forms from the otic capsule.

At about 29 to 32 days, tissue forms that will become the malleus and incus. By the 12th fetal week, the ossicles differentiate and are fully formed by the 16th week as cartilaginous structures begin to ossify. Almost total ossification of the malleus and incus has taken place by the 21st week. The 24th week shows rapid ossification of the incus and stapes. The middle-ear muscles derive from mesenchyme, the tensor tympani from the first arch, and the stapedius from the second arch.

Hearing Loss and the Middle Ear

Abnormalities of the middle ear produce conductive hearing losses. The air-conduction level drops in direct relationship with the amount of attenuation produced by the disorder. Theoretically, bone conduction should be unchanged from normal unless the inner ear becomes involved; however, our knowledge of middle-ear anatomy and physiology should make our

understanding of the effects of inertial bone conduction even clearer. Conductive hearing losses produced by middle-ear disorders may show alteration in the bone-conduction thresholds even without sensory/neural involvement. The amount of sensory/neural impairment in mixed hearing losses may be exaggerated by artifacts of bone conduction. These facts were demonstrated in a report by Orchik, Schumaier, Shea, and Xianxi (1995), where, in one case, the bone-conduction thresholds were significantly altered by a displacement of a prosthetic device used in middle-ear surgery.

8. As with the outer ear, disorders of the middle ear result in _____ hearing loss.

Disorders of the Middle Ear and Their Treatments

Negative Middle-Ear Pressure

Many, although not all, middle-ear disorders arise from poor function of the eustachian tube. Eustachian tube function may fail for a number of reasons. Two of the most common causes are edema of the eustachian tube secondary to infection or allergy and blockage of the orifice of the eustachian tube by hypertrophied (overgrown) adenoids. Structural abnormalities of the mechanism responsible for opening the tube are sometimes also present.

9. Negative middle-ear pressure is usually caused by some abnormality of the _____.

Any condition that interferes with the eustachian tube's function of equating air pressure between the middle ear and outer ear may result in a drop in pressure as the air trapped within the middle ear becomes absorbed by the tissues that line it without normal replenishment through the eustachian tube. When this absorption occurs, the greater pressure in the external auditory canal causes the tympanic membrane to be retracted (Figure 10.8). The retraction from eustachian-tube dysfunction (ETD) interferes with the normal vibration of the tympanic membrane and may produce a slight conductive hearing loss.

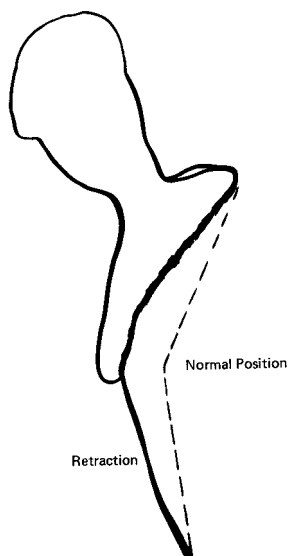


FIGURE 10.8 Retracted tympanic membrane caused by negative middle-ear pressure.

A method has been developed to use an immittance meter to test eustachian-tube function, if the tympanic membrane is intact, by using a pressure swallow technique (Williams, 1975). The patient is asked to swallow normally, after which a tympanogram is run. Then +400 daPa of pressure is applied to the membrane, and the patient is asked to swallow four times; a second tympanogram is then run on the same graph. Pressure is returned to 0 daPa and the patient swallows again to equalize middle-ear pressure. Finally, the patient is asked to swallow four times with -400 daPa in the external auditory canal, and a third tympanogram is run. If the eustachian tube is normal, the peaks of the three tympanograms will differ by at least 15 daPa. Differences smaller than this suggest dysfunction because the tube cannot equalize the middle-ear pressure.

When a retracted tympanic membrane is diagnosed and no infectious fluids are present in the nose, the otologist may elect to pressurize the middle ear through a process called **politzerization**.² One nostril is held closed while an olive tip, connected to a tube or nebulizer, is held tightly in the other nostril. The patient elevates the soft palate by saying “k-k-k” and then swallows; the otologist, meanwhile, observes the movement of the tympanic membrane during this process. In this fashion, tympanic membrane perforation or eustachian tube failure may be diagnosed.

The patient may autoinflate the eustachian tube by increased pressure on forced expiration with the nostrils held shut, a maneuver called **Valsalva**,³ that must be performed by divers as they descend or surface. Patients are often taught the Valsalva maneuver following middle-ear surgery. The **Toynbee maneuver**⁴ accomplishes eustachian tube opening when the patient closes the jaw, holds the nose, and swallows.

Figure 10.9 illustrates a mild conductive hearing loss in the left ear. The bone-conduction results are essentially normal, as are word-recognition scores. Results on all site-of-lesion tests would be expected to suggest conductive hearing loss. Acoustic immittance measurements show normal compliance in both ears, with a Type C tympanometric function in the left ear typical of negative middle-ear pressure (Figure 10.10). All of these findings are produced by the partial vacuum set up within the left middle-ear space.

Suppurative Otitis Media

One of the most common disorders of the middle ear causing conductive hearing loss is infection of the middle-ear space, or **otitis media**. Otitis media is any infection of the mucous-membrane lining of the middle-ear cleft. It is seen in nearly 70% of children born in the United States before they are 2 years old, with more than half of these children experiencing further episodes. The common cold is the only illness seen more frequently in children (Brooks, 1994).

Recent years have seen a dramatic increase in pediatric ear, nose, and throat infections (most frequently ear infections) caused by the difficult to treat methicillin-resistant staphylococcus aureus (MRSA) bacteria (Naseri, Jerri, & Sobol, 2009). MRSA is a strain of staph infection found to be highly resistant to broad-spectrum antibiotics. MRSA, which may be related to large-scale inappropriate use of antibiotics, can lead to dangerous, life-threatening invasive infections. Once limited mostly to nursing homes and healthcare settings, MRSA is frequently contracted within the community through direct skin-to-skin contact or contact with surfaces that have been contaminated with germs from cuts or open wounds.

Factors that predispose an individual to otitis media include poorly functioning eustachian tubes, **barotrauma** (sudden changes in air pressure, as when flying or diving), abnormalities in the action of the cilia of the mucous membranes, anatomical deformities of the middle ear and eustachian tube, age, race, socioeconomic factors, and the integrity of the individual's immune

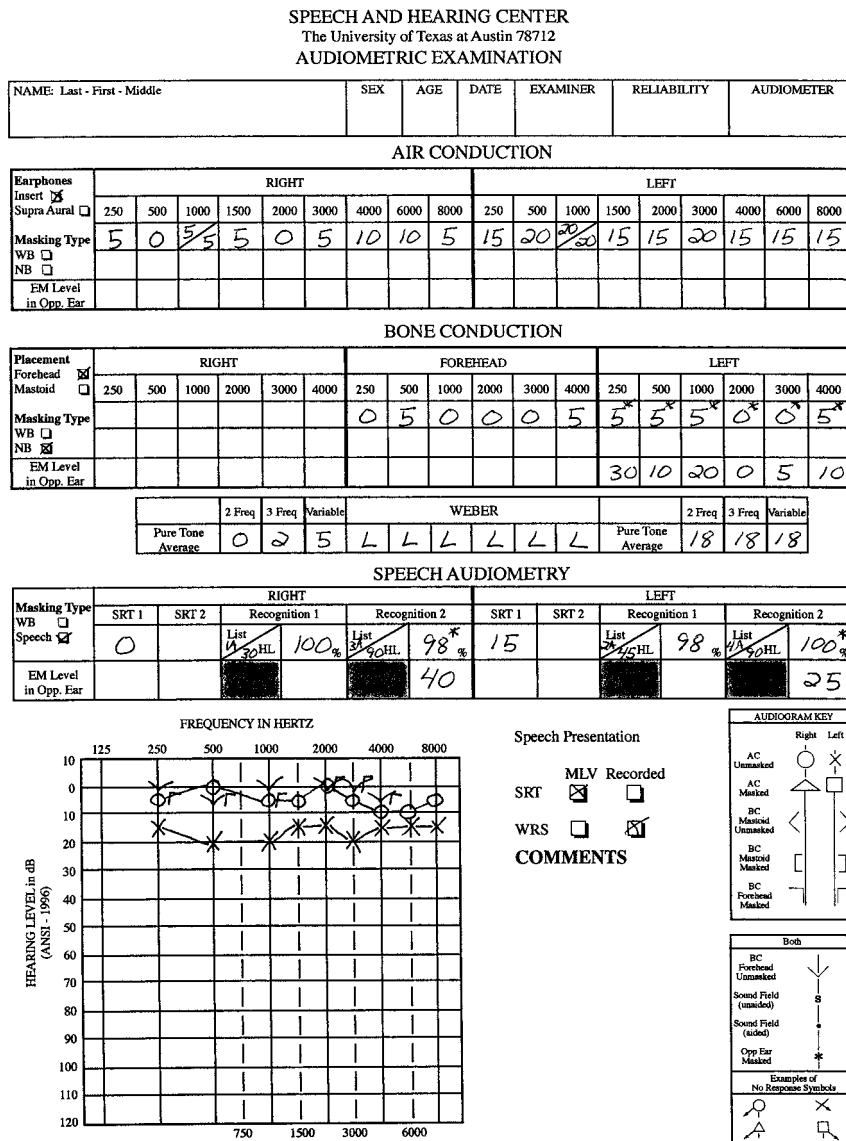


FIGURE 10.9 Audiogram illustrating a mild conductive hearing loss in the left ear produced by a retracted tympanic membrane. The right ear is normal. Masking was required for bone-conduction and word-recognition tests for the left ear. The Weber lateralizes to the left ear at all frequencies.

system. This last fact suggests that the growing epidemic of acquired immune deficiency syndrome (AIDS) will probably increase the incidence of otitis media. External factors associated with otitis media include exposure to cigarette smoke or other fumes. A link has been found between otitis media and Haemophilus influenza in the nasal passages of children. There is apparently also a gene that is linked to otitis media and so both treatment and avoidance techniques may change dramatically in the not-too-distant future.

Although otitis media is primarily a disease of childhood, it can occur at any age. There are clear seasonal effects (otitis media is most common in the winter months), but it is less clear why

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IMMITTANCE

NAME Last - First - Middle	SEX	AGE	DATE	EXAMINER	INSTRUMENT

ACOUSTIC REFLEXES

Frequency (Hz)	RIGHT				LEFT			
	500	1000	2000	4000	500	1000	2000	4000
Ipsilateral (Probe same)		90	85			NR	NR	
Contralateral (Probe opposite)	80	85	80	85	NR	NR	NR	NR
Audiometric Threshold	5	0	0	10				
Reflex SL	75	85	80	75				
Decay Time (Seconds)	10+	10+						

RIGHT					STATIC COMPLIANCE					Cx = C ₂ - C ₁
Tymp. Width	M.E. Pressure	C ₁ Volume	C ₂	C ₁ Compliance	Tymp. Width	M.E. Pressure	C ₁ Volume	C ₂	C ₁ Compliance	
100	0	.55	.99	.44	180	-200	.58	1.05	.47	

TYMPANOGRAMS

RIGHT

LEFT

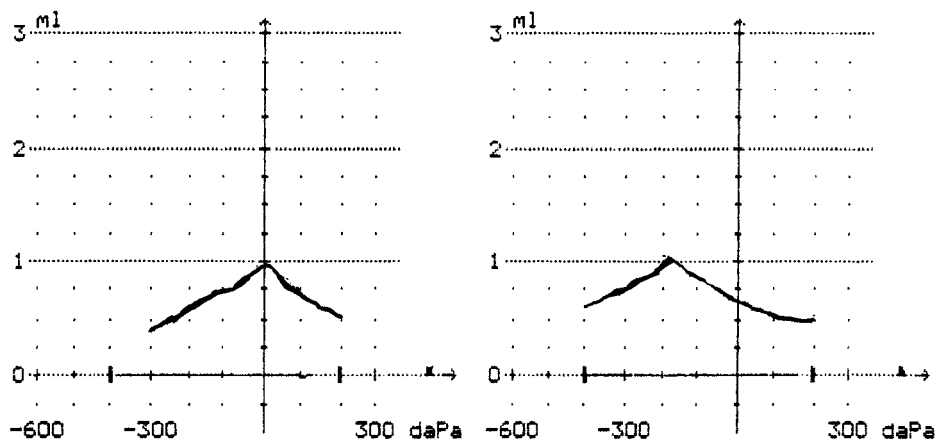


FIGURE 10.10 Typical results on immittance tests performed on a patient with a normal right-ear (Type A) and left negative middle-ear pressure (Type C). Static compliance is within the normal range for both ears. The right ipsilateral acoustic reflex threshold is normal, and the left ipsilateral acoustic reflex is absent. When the reflex-activating signal is introduced to the (normal) right ear (contralateral right stimulation), the acoustic reflex is shown here as present but may, in such cases, be absent. The hearing loss in the left ear causes the contralateral reflex to be absent when the RAS is presented to the left ear.

the disease is more common in males than in females. Also difficult to explain are the differences in incidence among racial groups. Otitis media is most common in Eskimos and Native Americans, less common in whites, and least common in blacks (Giebink, 1984). The interrelationships among socioeconomic, anatomical, and genetic differences are unclear.

As a rule, organisms gain access to the middle ear through the eustachian tube from the nasopharynx. They travel as a subepithelial extension of a sinusitis or pharyngitis, spreading the infection up through the tube. Often the infection is literally blown through the lumen of

the tube by a stifled sneeze or by blowing the nose too hard. In general, it is probably a good idea not to teach small children to blow their noses at all. They should also be encouraged to minimize pressure through the eustachian tube when sneezing by keeping their mouths open. Infection may also enter the middle ear through the external auditory canal if there is a perforation in the tympanic membrane. Bloodborne infection from another site in the body may occur, but this source of middle-ear infection is less common.

As stated earlier, infection usually begins at the orifice of the eustachian tube and spreads throughout the middle-ear cavity. When the tube is infected, it becomes swollen, interfering with its middle-ear pressure-equalization function. Also, when the tubal lining becomes swollen, the cleansing action of the cilia is compromised, and the infection is spread to adjacent tissues. A major contributing cause of otitis media, especially in children, is exposure to tobacco smoke. One study shows that in households in which more than three packages of cigarettes are smoked in a day, the risk to children of otitis media and other respiratory infections is four times more than it would be without such exposure (Kraemer et al., 1983).

Parents often report that as little as several hours may elapse between the appearance of initial symptoms and a full-blown infection in their children. In such rapidly progressing cases, it is probable that fluids that functioned as a culture medium for **purulent** (pus-producing) organisms had previously been deposited in the middle ear, perhaps from an earlier bacterial or viral infection. The rate of spread is also related to the virulence of the organisms.

In cases of otitis media, medical treatment is imperative. Proper diagnosis of the several usual stages can result in appropriate therapy. In the initial stage of eustachian tube swelling, causing occlusion of the tube, negative middle-ear pressure may be set up. The tympanic membrane may appear to be retracted (sucked in). Often audiometric examination reveals normal hearing on all tests. The tympanometric function may appear as a Type C, suggesting that the pressure within the middle ear is lower than that of the external auditory canal.

Before the actual accumulation of pus in the middle ear, the tympanic membrane and middle-ear mucosa may become very vascular. This inflammation produces the so-called “red ear” described by many physicians. If the condition is allowed to continue beyond this stage, suppuration (production of pus) may result. Enzymes are usually produced by bacterial infections, some of which have a dissolving effect on middle-ear structures.

In **suppurative** otitis media, the mucosa becomes filled with excessive amounts of blood, the superficial cells break down, and pus accumulates. Patients complain of pain in the ear, their pulse rates and body temperatures become elevated, and they are visibly ill. If pressure from the pus goes up, there will be compression of the small veins and capillaries in the middle ear, resulting in **necrosis** (death) of the mucosa, submucosa, and tympanic membrane. If the condition continues even further, the tympanic membrane may eventually rupture. Pus that cannot find its way out of the middle ear may invade the mastoid. The resulting **mastoiditis** causes a breakdown of the walls separating the air cells. Untreated mastoiditis can result in meningitis and sometimes death.

The general category of suppurative otitis media is frequently dichotomized by the terms **chronic** and **acute**. As a rule, the chronic form implies a condition of long standing. Symptoms of acute otitis media generally develop rapidly and include swelling, redness, and bleeding. Bleeding in the middle ear may also be caused by barotrauma, when there is a sudden pressure change, causing the blood vessels in the lining of the middle ear to rupture. Bleeding in the middle ear from any cause is called **hemotympanum**.

10. The general term for infection of the middle ear is _____.

11. In contrast to chronic otitis media, acute otitis media is of a _____ onset.

12. Otitis media, like many conductive hearing losses, will reveal a Type _____ tympanogram, and _____ acoustic reflexes.

Audiometric Findings in Suppurative Otitis Media. Otitis media results in the typical audiogram of the conductive hearing loss (Figure 10.11). Generally, the amount of hearing loss is directly related to the accumulation of fluid in the middle ear. The audiometric contour is usually rather flat, showing approximately equal amounts of hearing loss across frequencies. Word-recognition scores are generally excellent, although proper masking must often be instituted to ensure against cross-hearing. Bone-conduction results are usually normal.

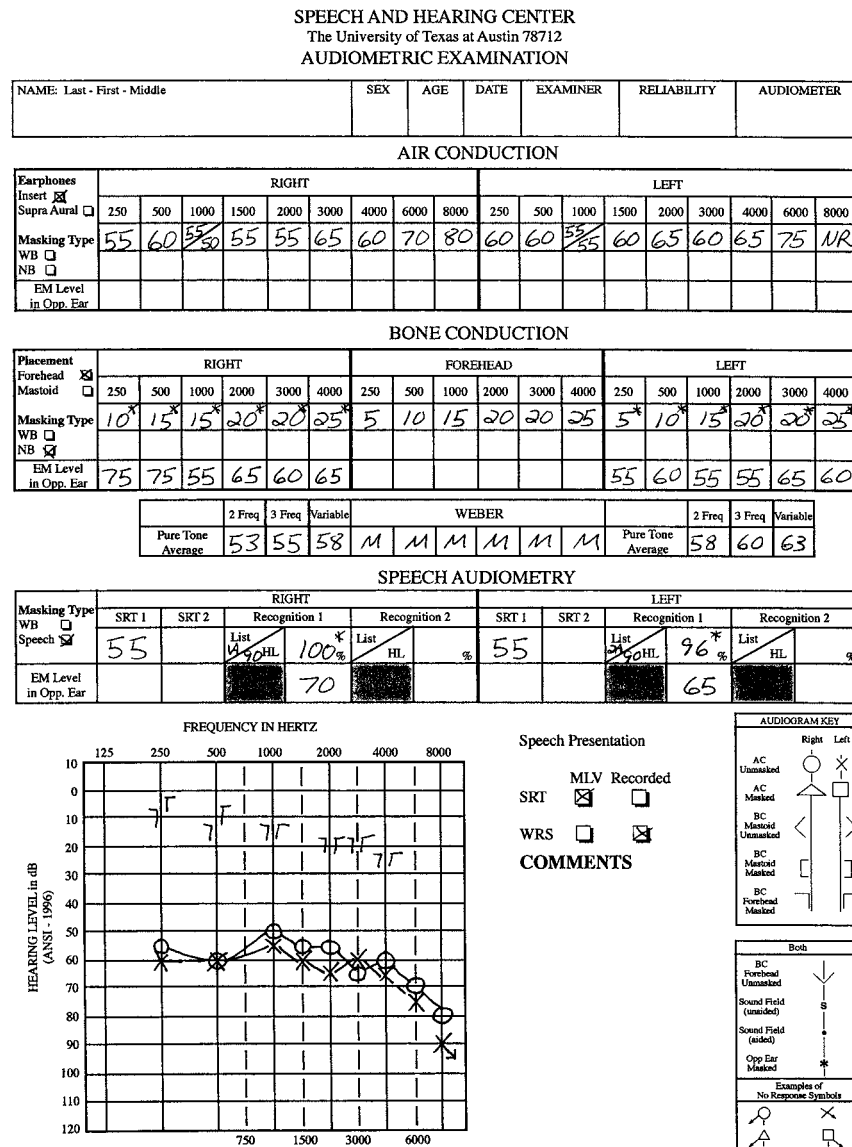


Figure 10.11 Audiogram illustrating a moderate conductive hearing loss in both ears. The contour of the audiogram is relatively flat, and fairly typical of otitis media. Word-recognition scores are excellent. Note that masking is not necessary for air conduction or SRT because insert receivers are used that provide significant interaural attenuation. Masking is required for bone-conduction tests and word-recognition testing.

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IMMITTANCE

NAME Last - First - Middle	SEX	AGE	DATE	EXAMINER	INSTRUMENT

ACOUSTIC REFLEXES

Frequency (Hz)	RIGHT				LEFT			
	500	1000	2000	4000	500	1000	2000	4000
Ipsilateral (Probe same)		NR	NR			NR	NR	
Contralateral (Probe opposite)	NR	NR	NR	NR	NR	NR	NR	NR
Audiometric Threshold								
Reflex SL								
Decay Time (Seconds)								

STATIC COMPLIANCE

		RIGHT			LEFT			$C_0 = C_2 - C_1$	
Tymp Width	M.E. Pressure	C_1 Volume	C_2	C_0 Compliance	Tymp Width	M.E. Pressure	C_1 Volume	C_2	C_0 Compliance
115	NA	.61	.90	.19	115	NA	.53	.70	.17

TYMPANOGRAMS

RIGHT

LEFT

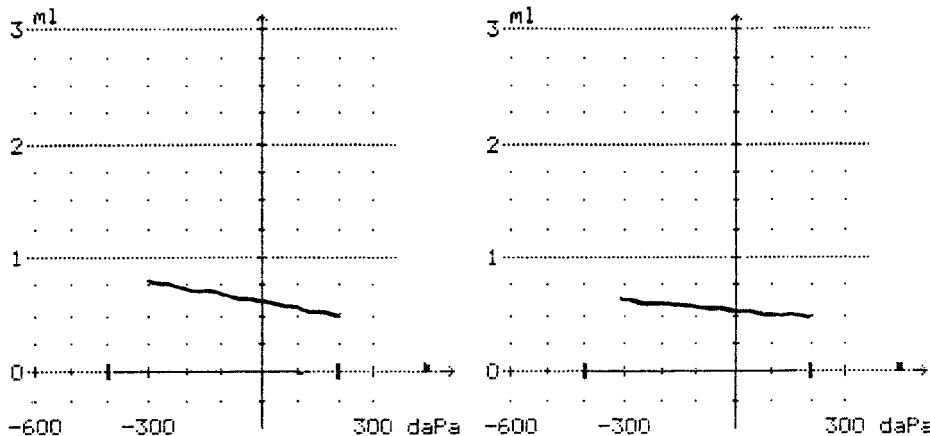


Figure 10.12 Typical results on immittance tests performed on a patient with bilateral otitis media or serous effusion (see Figure 10.11). Note that the tympanogram is Type B, tympanometric width is high, the static compliance is low, and acoustic reflexes are absent in both ears.

Measurements of static compliance show lower-than-normal values. The tympanometric function is a Type B (Figure 10.12), suggesting the presence of fluid behind the tympanic membrane. Acoustic reflexes cannot be elicited in either ear because the intensity of each reflex activating stimulus, even at maximum levels of the immittance meter, is below the acoustic reflex threshold. Additionally, abnormalities of the middle ear cause increased impedance of the ossicular chain, which resists movement in response to contraction of the stapedius muscle. Figure 10.13 shows that the latencies of all the waves resulting from ABR testing are increased at all sensation levels. No otoacoustic emissions can be evoked (Figure 10.14).

There are times when ABR testing is carried out by bone conduction in order to verify the existence and magnitude of a suspected conductive component of a hearing loss in a patient who

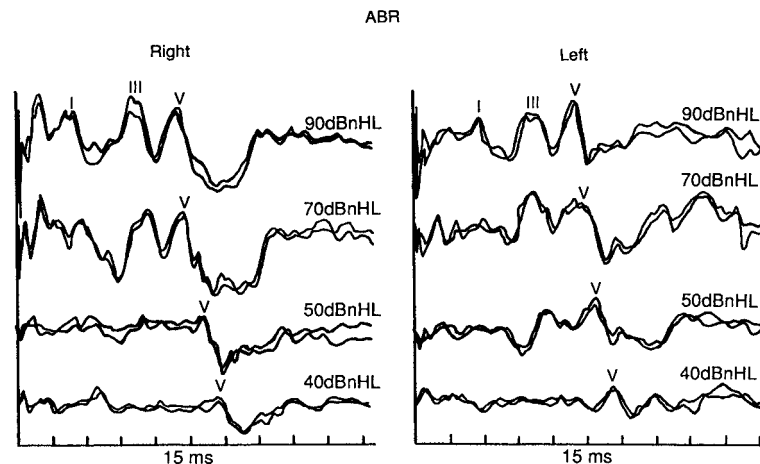


FIGURE 10.13 Results of auditory brain-stem response testing on the patient with a bilateral conductive hearing loss caused by otitis media (see Figure 10.11).

cannot cooperate on behavioral tests. In such cases, while the air-conduction ABR would look like Figure 10.13, results of the normal bone-conduction ABR would look like Figures 7.13 and 7.14. If audiologists plan to do bone-conduction ABR audiometry, they should remember to norm their equipment using a bone-conduction oscillator in addition to an air-conduction receiver since the correction factors are different for normal-hearing persons. It must also be remembered that for testing ABR on infants the mastoid, rather than the forehead, is the preferred testing site since the sutures in the skull may not be closed, creating a larger-than-normal disparity between mastoid and forehead results.

Many or all of the audiometric results that point so clearly to otitis media as the cause of the conductive hearing loss shown in Figures 10.9 and 10.11 may be unattainable in the infant or small child. However, with a minimal amount of patient cooperation, measurements of static compliance and tympanometry can be obtained and may suggest the presence of middle-ear infection.

Antibiotic Treatment of Otitis Media. Bacterial infections, like those found in otitis media, survive by multiplication. Each bacterial cell forms a protective capsule around itself to ensure its survival. Some antibiotics kill the bacteria directly. Other antibiotics serve to inhibit the formation of the protective covering, thereby limiting the growth within the bacterial colony and allowing the white blood cells to surround and carry off the bacteria. When a substantial pocket of infection exists, as in suppurative otitis media, the mass of bacteria, by virtue of numbers alone, may resist a complete bacteria-killing action. Different drugs are specific to different organisms, and unless the appropriate drug is prescribed, the action may be less than useful. Modern laboratory facilities allow for culturing the organism causing the infection, so that the physician may take advantage of the specificity of a given antibiotic. One problem in using antibiotics when a pocket of infected fluid exists in any part of the body is that the antibiotics travel through the bloodstream and have difficulty passing from the bloodstream to the site of the infection.

When the middle ear is filled with pus, produced by the body to carry cells to the area to ingest the bacteria, frequently the best procedure is to remove the pus, rather than to rely completely on the effects of antibiotics. As long as the tympanic membrane remains intact, drops in the external ear canal can have no therapeutic effect in cases of otitis media because the drops cannot reach the infection.

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NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	INSTRUMENT

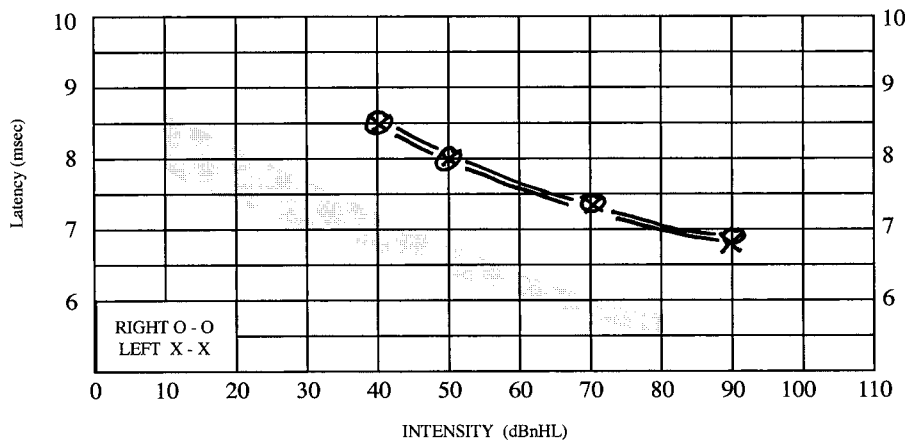
OTOACOUSTIC EMISSIONS
(Present or Absent)

☒ TEOAE Level 80 dB Peak SPL
☐ DPOAE Level F₁ ____ F₂ ____

Right					Left				
500	1000	2000	4000	6000	500	1000	2000	4000	6000
A	A	A	A	A	A	A	A	A	A

AUDITORY BRAINSTEM RESPONSE

ABR WAVE V LATENCY-INTENSITY FUNCTION



EAR	nHL		Absolute Latency (ms)			Interpeak Latency (ms)			Latency Change w/ Increased Rate	
	dB HL	Click Rate	I	III	V	I-III	III-V	I-V	V	Click Rate
RIGHT	90	33.1	2.7	5.1	6.85	2.4	1.75	4.15		
LEFT	90	33.1	2.8	5.0	6.8	2.2	1.8	4.0		
Interaural Differences										

Amplitude Ratio (V same or > I)

R NL L NL

Estimated Air Conduction Threshold

R <40 L <40

Estimated Bone Conduction Threshold

R ____ L ____

FIGURE 10.14 Objective hearing test results showing absent otoacoustic emissions because of a conductive hearing loss (see Figure 10.11). Latency-intensity functions for wave V are shown as derived from the auditory brain-stem response tracings shown in Figure 10.13 on the patient with a bilateral conductive hearing loss. The latencies of all waves are increased at all levels tested.

Dormant Otitis Media

The introduction of antibiotics at the close of World War II drastically altered the treatment of otitis media. Although antibiotics have dramatically decreased the number of serious effects of otitis media, they have also had some undesirable side effects. Unless the proper type and dosage of antibiotics are used, the disease may go not to resolution but to a state of quiescence. Because the overt symptoms may disappear, both the physician and patient may assume a complete cure. Several weeks later the patient may experience what seems like a whole new attack of otitis media, which is in reality an exacerbation of the same condition experienced earlier, but allowed to lie dormant. Many patients discontinue their own antibiotic treatments when their symptoms abate, leaving some of the hardier bacteria alive. Then, when the condition flares up again, it is the result of a stronger strain, less susceptible to medication. Antibiotics, therefore, may lead to a false sense of security in the treatment of otitis media and mastoiditis.

Serous Effusion of the Middle Ear

If a partial vacuum in the middle ear is allowed to continue, the fluids normally secreted by the mucous-membrane lining of the middle ear may literally be sucked into the middle-ear space, resulting in serous effusion. As the fluid level rises, otoscopic examination reveals the presence of a fluid line, called the **meniscus**, visible through the tympanic membrane. As the fluid pressure continues to increase, and the level rises, the tympanic membrane may return to its normal position when the meniscus rises above the superior margin of the tympanic membrane. At this stage the condition is sometimes difficult to diagnose visually.

When fluid fills the middle-ear space, a Type B tympanometric function results (Figure 10.12). This function occurs because no amount of air pressure delivered to the tympanic membrane from the pump of the immittance meter can match the pressure on the middle-ear side of the tympanic membrane. Because a serous accumulation in the middle ear affects the mass of the system, it is expected that the audiogram will initially show a greater loss for higher- than for lower-frequency sounds (Figure 10.15). It is likely that the slightly depressed bone-conduction thresholds in Figure 10.15 are artifacts produced by the fluid in the middle ear. Post-treatment audiograms would probably show a disappearance of the air-bone gap and some improvement in the bone-conduction thresholds.

Because serous effusion is often secondary to a poorly functioning eustachian tube, drug therapy, including decongestants or decongestant-antihistamine combinations, has long been used to restore normal middle-ear pressure and to help clear the tube of secretions. However, decongestants are now believed to be virtually useless for this purpose in infants and small children, whose eustachian tubes are less efficient than those of adults. As the middle ear may not be actively infected during serous effusion, antibiotics frequently are not indicated. However, some physicians prescribe antibiotics prophylactically because the fluid, though sterile, may serve as a culture base for bacterial infection. There is evidence that the three organisms most associated with otitis media in children have become resistant to the most commonly used antibiotics (Brooks, 1994). Even if antibiotics destroy the organisms causing the condition, they cannot eliminate the fluids that have formed in the middle-ear space.

13. The accumulation of fluid in the middle ear is more common in babies than in older children and adults because the eustachian tube is _____.

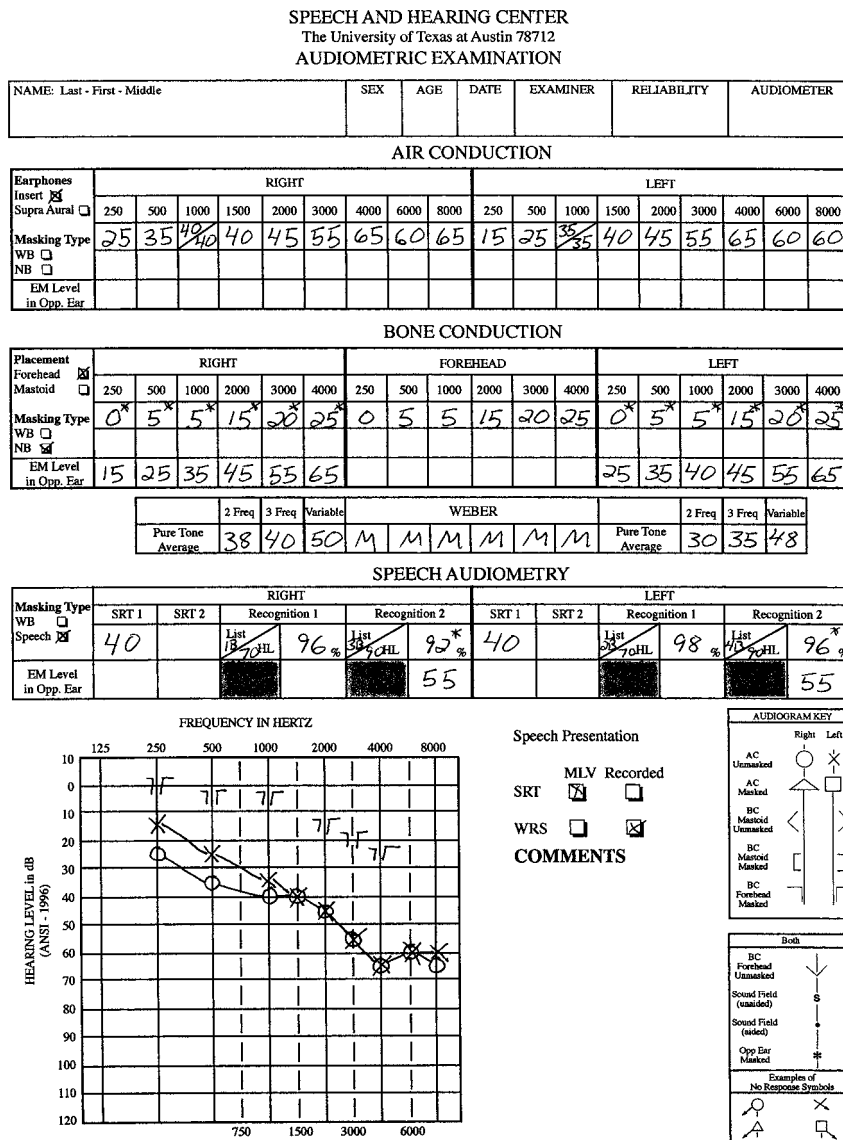


FIGURE 10.15 Audiogram illustrating conductive hearing loss in both ears produced by serous effusion. Note that masking was needed at all frequencies for bone conduction and word recognition. Speech recognition is normal, the Weber does not lateralize, and the audiogram falls noticeably in the higher frequencies.

Clinical Commentary

Decongestants are frequently prescribed in cases of middle-ear fluid to promote drainage through the eustachian tube. In young children such treatments may be less successful because the eustachian tube is relatively horizontal compared to the steeper angle attained by age 6 or 7 years. It is the slight angle of eustachian tubes of young children that leads to a greater propensity for fluid accumulation in their middle ears.

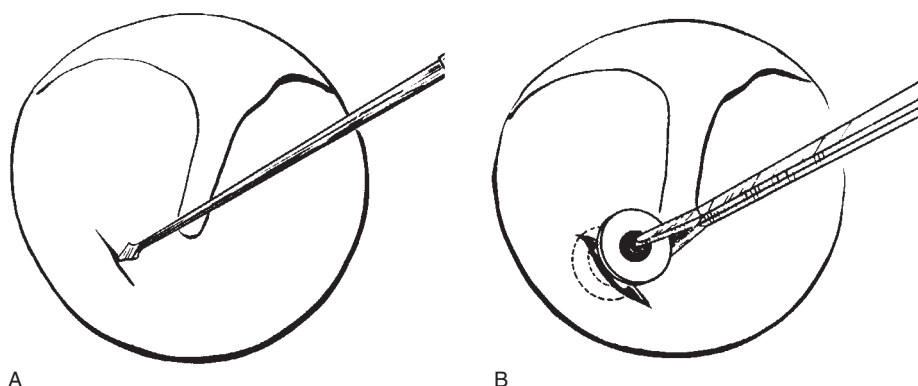


FIGURE 10.16 (A) A myringotomy incision. (B) A pressure-equalizing tube positioned through the tympanic membrane to allow for middle-ear ventilation. (Courtesy of Arkansas Otolaryngology Center)

Surgical Treatment for Middle-Ear Fluid. In the days predating antibiotics, therapy for otitis media was primarily surgical. Today surgery is still required in many cases. The primary purpose of surgery for patients with infection in the middle ear is to eliminate disease. Reconstructing a damaged hearing apparatus is an important, but secondary, goal.

If the fluid pressure continues to build within the middle ear, perforation of the tympanic membrane becomes a threat. If perforation appears imminent or disease-laden fluids are present in the middle ear and must be removed, the otologist may elect to perform a myringotomy, or myringostomy (incision into the tympanic membrane) to relieve the fluid pressure and suction out the remaining fluid. Frequently, a plastic **pressure-equalizing (P.E.) tube** is inserted through the incision in the tympanic membrane to keep the middle ear patent. Figure 10.16 shows a myringotomy incision and a P.E. tube in position. A photograph of one kind of P.E. tube is shown in Figure 10.17. The derivation of the word myringotomy is from *myringa*, modern Latin for drum membrane, and *tome*, Greek for cutting. It is also called myringocentesis, tympanotomy, tympanostomy, or paracentesis of the tympanic membrane. Myringotomy is frequently performed as a simple office operation, but at times, especially with some small children, it requires brief hospitalization. An incision is made with a special knife, generally in the inferior-posterior quadrant of the tympanic membrane. As in the discussion of serous effusion, the fluids are removed by a suction tip placed through the incision. If myringotomy is performed on small children while they are awake, they must be immobilized sufficiently so that any sudden movement does not redirect the action of the knife, which could possibly cause damage to the middle ear. As a rule, children are lightly anesthetized for the procedure. Wilder and colleagues (2009) have reported a possible association between repeated surgical procedures with anesthesia prior to 4 years of age and the development of learning disabilities. It remains uncertain whether anesthesia was the determining factor in learning disabilities in the children studied or whether the condition requiring surgical intervention with anesthesia is a marker for unidentified contributing factors to the development of learning disabilities, so this is a subject requiring further inquiry.

Many individuals believe that the purpose of the P.E. tube is to permit fluid drainage from the middle ear. The actual function of the tube is to allow for direct ventilation of the middle ear, and it functions as an artificial eustachian tube to maintain normal middle-ear air pressure. The plastic tube provides a second vent to the middle ear, which acts much in the same way as the second hole punched in the top of a can of liquid. Air may enter the middle ear via the tube, allowing drainage down the eustachian tube. The tubes may remain in position from several weeks to

14. The purpose of P.E. tubes is to _____.

14. normalize middle-ear pressure



FIGURE 10.17 A pressure-equalizing tube for insertion through a myringotomy incision in a tympanic membrane to allow middle-ear drainage and ventilation. It is shown next to a penny to illustrate its small size.

several months, after which time some types extrude naturally and fall into the external auditory canal. In the interim, the eustachian tube problem should be appropriately handled when possible through adenoidectomy, allergic desensitization, or whatever medical means seem to be indicated.

To avoid multiple myringotomies in patients with unresolving eustachian tube problems, a new tube has been developed that can stay in position almost indefinitely (Figure 10.18). Although surgical insertion is more complicated and lengthy than with the traditional P.E. tubes, the clinical experience with these Teflon-lined tubes holds promise for better long-term relief (Jahn, 1993).

Some otologists have found that tubes remain in position longer if they are placed in the superior-anterior quadrant of the tympanic membrane, because there is less migration of epithelium in this area than in the larger inferior quadrants. Positioning the tube in this superior area requires the use of a surgical microscope. Failure to resolve the eustachian tube difficulty will frequently lead to a recurrent attack of serous effusion.

An actual myringotomy (myringostomy) with tube insertion can be seen in the video titled “Myringostomy” in the Clinical Demonstrations section on the Companion Website.

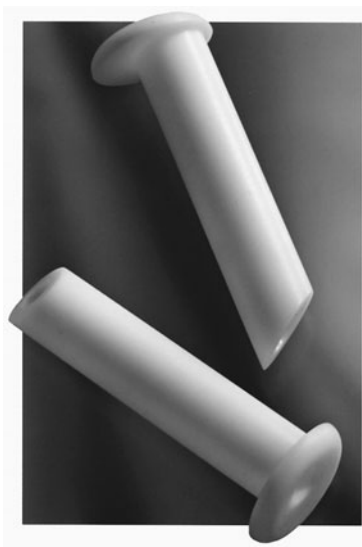


FIGURE 10.18 One of several styles of middle-ear ventilation tubes designed to stay in position in the tympanic membrane for long periods for cases of nonresolving eustachian-tube dysfunction. (Courtesy of Gyrus ENT, LLC)

15. The patency of P.E. tubes can be verified through the _____.

Immittance Testing for Tube Patency and Eustachian Tube Function. Acoustic immittance meters can be very useful in diagnosing perforations of the tympanic membrane, even those too small to be seen with an ordinary otoscope (Chapter 7). The **physical-volume test (PVT)** can be used in the same way to test the patency of pressure-equalizing tubes placed through the tympanic membrane. If the clinician observes that c_1 is an unusually large value, in excess of 5 cm^3 , it may be assumed that this measurement is of a cavity that includes both the outer-ear canal and the middle ear. Of course, many patients, especially children, have tympanic membrane perforations or open P.E. tubes and show less than 4 cm^3 as the c_1 value.

Immittance meters may be used to determine the very important matter of eustachian tube function. The tests are rapid and objective, and they take considerably less time than more elaborate methods. The patient is instructed to prevent eustachian tube opening during the test by not swallowing and by remaining as motionless as possible. The test is designed for patients with tympanic membrane perforations or with patent pressure-equalization tubes in place.

The first step is to establish a pressure of $+200 \text{ daPa}$ and to have the patient open the tube by swallowing or yawning. If the tube opens, pressure equalization will take place in the middle ear and the manometer will indicate a shift toward 0 daPa . Eustachian tube function has been qualified by Rock (1974) as “good,” “fair,” or “poor,” depending on the degree to which the pressure is reduced by this maneuver. According to Gladstone (1984), the eustachian tube function test must be performed with positive air pressure in the external auditory canal because negative pressure could cause the tube to “lock” shut rather than be forced open.

Mucous Otitis Media

At times, thick mucoid secretions, often forced through the eustachian tube by sneezing or excessive pressure when blowing the nose, accumulate in the middle ear. If these secretions are allowed to remain, they may become dense and darken in color. This condition, which has been referred to as “glue ear,” produces the same kind of audiometric results as suppurative otitis media. After some period of time, however, the hearing loss is not reversible by simple myringotomy. Even after the inflammatory process has been removed, imperfect healing of the tissue may leave scars. The tissues forming these scars may be fibrous in nature, resulting in a network or web of adhesions. These adhesions cause particular difficulty because they may bind any or all of the ossicles. In addition to the adhesions in the middle ear, calcium deposits sometimes form on the tympanic membrane, resulting in a condition called **tympanosclerosis**. Surgical dissection of adhesions in the middle ear may be fruitless because they tend to recur, causing conductive hearing loss. According to Meyerhoff (1986), mucous otitis media is more common in younger children, whereas serous effusion is more common in older children.



Color photographs of an ear with tympanosclerosis and ears with a variety of other pathologic conditions may be found in the Learning Supplements section under “Ear Pathology” on the Companion Website.

Cholesteatoma

Whenever skin is introduced to the middle-ear cleft, the result may be a pseudotumor called **cholesteatoma**. Cholesteatomas form as a sac, with onionlike concentric rings made up of keratin (a very insoluble protein) mixed with squamous (scaly) epithelium and with fats such as cholesterol. In patients with perforated tympanic membranes, the skin may enter the middle ear through the perforations. This invasion produces a secondary acquired cholesteatoma. A primary acquired cholesteatoma may occur without a history of otitis media if the epithelium of the attic of the middle ear becomes modified. This alteration may occur if the pars flaccida of the tympanic membrane becomes sucked into the middle ear through negative pressure and then opens, revealing the skin from the outer portion of the tympanic membrane to the middle ear.

Cholesteatomas may also enter the middle ear in several other ways. In any case, they may be extremely dangerous. They have been known to occupy the entire middle ear and even pass down through the opening of the eustachian tube into the nasopharynx or up into the brain cavity. They are highly erosive and may cause destruction of bone and other tissue.

Although antibiotics may arrest otitis media, and even mastoiditis, the best treatment for cholesteatoma is still surgery. The condition spreads rapidly, and the surgeon must be absolutely certain that all the cholesteatomatous material has been removed, because if even a small amount remains, the entire condition may flare up again in a short period of time. Most ears with cholesteatomas are secondarily infected and produce foul-smelling discharges that drain from the ears (**otorrhea**).

Mastoidectomy

Even with modern drug therapy, at times the only treatment for mastoiditis is a surgical procedure called **mastoidectomy**, usually performed under general anesthesia. In earlier days the incision was made behind the auricle, and the bone in the mastoid process was scraped until all the infection was removed. This technique frequently resulted in a large concavity behind the ear. The surgically created mastoid bowl required cleaning for the rest of the patient's life and was in itself a breeding ground for infection.

The modern surgical approach to mastoidectomy is to avoid creating a mastoid cavity whenever possible. When a mastoid cavity does exist, it can often be obliterated by using portions of the temporalis muscle and/or bone chips taken from the patient. The obliteration of the mastoid cavity may be done at the time of initial surgery, or it may be staged at a later date, depending on the disease process found in the mastoid. Mastoidectomies are also performed sometimes in the absence of actual infection to repair paralyzed facial nerves. This procedure has been found to be very gratifying in recent years.

Tympanoplasty

Surgical reconstruction of the middle-ear auditory apparatus is called **tympanoplasty**. The simplest form of tympanoplasty is myringoplasty, repair of the tympanic membrane described in Chapter 8. Many surgical approaches have attempted to substitute metal or plastic prosthetic devices for damaged or missing ossicles. These attempts have met with limited success because the body tends to reject foreign materials. In recent years tympanoplasties have been performed by attaching existing middle-ear structures together. This attachment may mean the loss of the function of one or more ossicles. The surgeon

16. True/False
The primary purpose for performing a tympanoplasty is restoration of the patient's hearing to as great an extent as possible.

may place the tympanic membrane directly on the head of the stapes to restore a remnant of ossicular chain function.

Hearing improvement following tympanoplasty varies considerably, depending on the preoperative condition of the middle ear and, to a great extent, on the functioning of the eustachian tube. If the tube fails to function properly, and the middle ear is not normally pressurized, the surgical procedure is almost certainly doomed to failure.

Sometimes, though rarely, a patient's hearing may be poorer following surgery. The surgeon may have found, for example, that the long process of the incus is necrosed, but instead of there being a hiatus between the body of the incus and the stapes, the gap has been closed by a bit of cholesteatoma. Removal of the cholesteatoma is necessary, even though the result is interruption of the ossicular chain and increased hearing loss. Patients to whom this has happened may be difficult to console.

Audiograms of patients with interrupted ossicular chains show all the expected findings consistent with conductive hearing loss. The compliance of the tympanic membrane in such cases is unusually high because it has been decoupled from the stapes. The expected pressure-compliance function is a Type A_D (Figure 10.19).

Although static-compliance values may not in themselves determine the presence of a conductive problem in the middle ear, comparison of c_x in the right and left ears of the same patient may be extremely useful. De Jonge and Valente (1979) suggest that when the static-compliance difference between ears exceeds 0.22 cm³, a conductive problem may exist in one ear, even if both values fall within the normal range. However, differences exceeding this value can certainly exist in patients with normal hearing.

Anderson and Barr (1971) reported on high-frequency conductive hearing losses that may result from **subluxations** (partial dislocations) in the ossicular chain. When a portion of one of the ossicles is replaced by soft connective tissue, the elasticity of this connection, acting as an insulator against vibrations, transmits low frequencies more easily than high frequencies. Hearing losses caused by this condition are usually mild and result in an elevated acoustic reflex threshold.

Facial Palsy

In some cases of chronic otitis media, the bony covering of the fallopian canal becomes eroded, exposing the facial nerve to the disease process. Damage to the facial nerve may result in a flaccid paralysis of one side of the face. Appropriate treatment often includes middle-ear surgery.

At times, unilateral facial paralysis results when no other clinically demonstrable disease is present. Although there are several theories about why the paralysis, called **Bell's palsy**,⁵ occurs, the reason is probably related to the blood supply to the nerve or to viral infection. A diagnosis of Bell's palsy is made by ruling out any other causative lesion in a patient with a flaccid facial paralysis. Bell's palsy resolves spontaneously in the majority of cases.

17. Facial paralysis is caused by disorder of the _____ cranial nerve.

Patulous Eustachian Tube (PET)

There are some individuals in whom the eustachian tube is chronically patent (open), which often results in the sensation of **autophony**, the "head-in-a-barrel" feeling. As a result, their own voices are perceived as loud. This condition is observed more often in females than in males and has been associated with pregnancy. Some patients have claimed that their distorted autophony

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IMMITTANCE

NAME Last - First - Middle	SEX	AGE	DATE	EXAMINER	INSTRUMENT

ACOUSTIC REFLEXES

Frequency (Hz)	RIGHT				LEFT			
	500	1000	2000	4000	500	1000	2000	4000
Ipsilateral (Probe same)		NR	NR			95	85	
Contralateral (Probe opposite)	NR	NR	NR	NR	NR	NR	NR	NR
Audiometric Threshold								
Reflex SL								
Decay Time (Seconds)								

STATIC COMPLIANCE

RIGHT				LEFT				C ₀ = C ₁ - C ₂	
Tymp. Width	M.E. Pressure	C ₁ Volume	C ₁ Compliance	Tymp. Width	M.E. Pressure	C ₁ Volume	C ₁ Compliance	C ₂ Volume	C ₂ Compliance
120	0	.48	240	100	0	.41	.82		.41

TYMPANOGRAMS

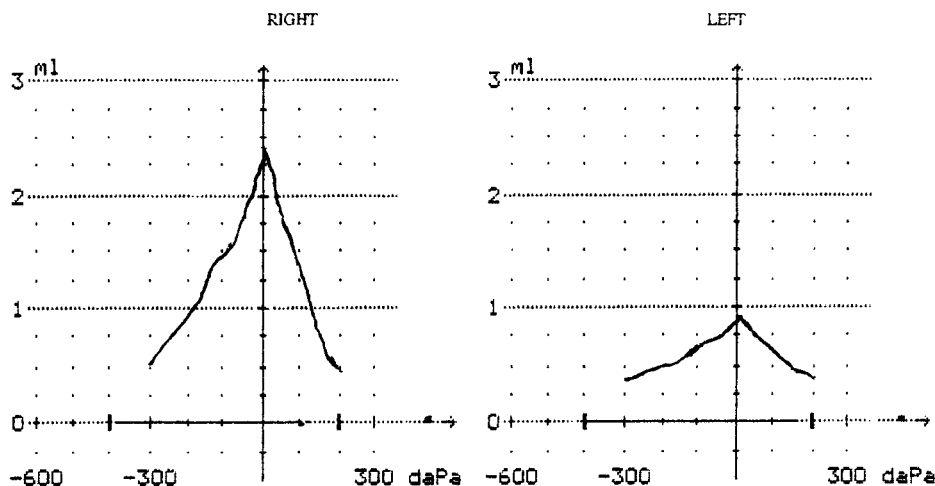


FIGURE 10.19 Typical results on immittance tests performed on a patient with right ossicular chain discontinuity. Note that the tympanogram is Type AD (normal middle-ear pressure but extremely compliant tympanic membrane), the static compliance is high, and contralateral reflexes are absent in both ears as is the right ipsilateral reflex. The left ear is normal in this case.

causes an echoing effect that interferes with their speech production. Other annoying effects of patulous eustachian tube include the sound of breathing and noises during chewing as the sound travels up the tube. Causes ascribed to this condition include the hormonal changes brought on by pregnancy or the use of some birth control pills, sudden changes in body weight, the use of decongestant medications, temporomandibular joint syndrome, and stress (O'Conner & Shea, 1981).

The problem of patulous eustachian tubes is more widespread than many people realize, and the incidence may go as high as 30% of people with otherwise normal ears (Kumazawa, 1985). Ten percent of a group of women studied had patulous eustachian tubes

18. True/False
Patient complaint of a "head-in-a-barrel" sensation is often caused by a patulous eustachian tube.

during pregnancy (Plate, Johnsen, Pederson, & Thompson, 1979). Misdiagnosis is common because patients' complaints often make the condition sound like **serous effusion** or a blocked eustachian tube, resulting in completely inappropriate treatment.

If the patient suffers from a chronically patent eustachian tube and exhibits a Type A tympanogram, a simple test can verify the problem. Tympanic membrane compliance is observed during nasal breathing, oral breathing, and momentary cessation of breathing. If the tube is open, the compliance will increase during inhalation and decrease during exhalation. Interruption in breathing stops the changes in compliance. Henry and DiBartolomeo (1993) found tympanometry to be a useful tool in the diagnosis of patulous eustachian tube.

Otosclerosis

Otosclerosis, a common cause of hearing loss in adults, is hereditary in at least 70% of all cases (Morrison & Bunday, 1970). The condition originates in the bony labyrinth of the inner ear and is recognized clinically when it affects the middle ear, causing conductive hearing loss. Otosclerosis is a progressive disorder, with a varying age of onset from mid-childhood to late middle-adult life. The great majority of patients begin to notice some loss of hearing soon after puberty, up to 30 years of age. Otosclerosis is rare among children. It occurs primarily among members of the white race, with the incidence in women approximately twice that in men. Women frequently report increased hearing loss caused by otosclerosis during pregnancy or menopause.

19. True/False
Otosclerosis is
frequently hereditary
and is more common in
women than in men.

Otosclerosis appears as the formation of a new growth of spongy bone, usually over the stapedial footplate of one or both ears. Because the bone is not really sclerotic (hard), some clinicians call this condition (more appropriately) **otospongiosis**. When this growth occurs, the footplate becomes partially fixed in the oval window, limiting the amplitudes of vibrations transmitted to the inner ear. At times the growth appears on the stapedial crura or over the round window. Very rarely does it occur on other ossicles or occupy considerable space in the middle ear. Sometimes the abnormal bone, which replaces the normal bone of the middle ear, may completely obliterate the margins of the oval window.

Patients with otosclerosis often exhibit a bluish cast to the whites of their eyes, similar to that found with certain other bone diseases. They complain of difficulty hearing while chewing, probably a result of the increased loudness of the chewing sounds delivered to their inner ears by bone conduction. Frequently, they are also bothered by sounds called **tinnitus** in the affected ear(s). The hearing loss itself is usually slowly progressive. Physical examination of the ear shows normal structures and normal tympanic membrane landmarks. Occasionally, the promontory becomes very vascular, resulting in a rosy glow that can be seen through the tympanic membrane. This glow is referred to as the **Schwartz sign**.

One interesting and peculiar symptom of otosclerosis is **paracusis willisii**. Most patients who are hard of hearing claim they hear and understand speech better in quiet surroundings. Patients with otosclerosis, on the other hand, (and often those with other forms of conductive hearing loss) may find that speech is easier to understand in the presence of background noise. This phenomenon results from the fact that normal-hearing persons speak louder in noisy environments. This increase in vocal loudness, something we have all experienced, is called the **Lombard voice reflex**. Because these patients' hearing losses attenuate the background noise to some degree, such people are able to enjoy the increased loudness of speakers' voices with less distracting noise.

Audiometric Findings in Otosclerosis. Carhart (1964) showed that the first symptom of otosclerosis is the appearance of a low-frequency air-bone gap. He also found that alterations in the inertia of the ossicular chain, produced by even partial fixation, alter the normal bone-conduction response. This artifact varies significantly from patient to patient, but on the average it causes the bone-conduction readings to appear poorer than the true sensory/neural sensitivity by an average of 5 dB at 500 Hz, 10 dB at 1000 Hz, 15 dB at 2000 Hz, and 5 dB at 4000 Hz, although the frequency with the greatest bone-conduction suppression is not always 2000 Hz. This anomaly of bone conduction is called the **Carhart notch** (Carhart, 1952) and probably occurs as a mechanical artifact because of the loss of the inertial mode of bone conduction and a shift in the normal resonant frequency of the middle ear, which ranges from 630 to 2000 Hz (Margolis & Goycoolea, 1993), all produced by the immobility of the oval window. The Carhart notch is also seen in some cases of middle-ear fluid.

Figure 10.20 illustrates an audiogram typical of early otosclerosis. Contrary to the typical audiometric contour in serous effusion, the otosclerotic patient shows a drop in hearing sensitivity in the low-frequency areas first, which is consistent with what is known of the effects of stiffness on impedance. As the principal site of otosclerosis increases in size, the hearing loss becomes greater (Figure 10.21). Later in the disease, when the stapes has become more completely fixed, the mass effect becomes apparent, causing a reduction of sensitivity in the high frequencies, thus flattening the audiogram. With complete fixation, the entire mass of the skull is in fact added to the stapes. All auditory tests for site of lesion remain consistent with conductive hearing loss.

The pressure-compliance function remains normal in otosclerosis, except that the point of greatest compliance is shallower compared to the normal tympanogram. Jerger (1970) has called this type of tympanogram (Figure 10.22) a Type A_s (stiffness). The A_s tympanogram appears in many, but not all, cases of otosclerosis. The acoustic reflex disappears early in otosclerosis, even in unilateral cases. When the tone is delivered to the involved ear, the hearing loss attenuates even a very intense sound, so that the reflex is not triggered. When a tone is delivered to a normal ear opposite the one with otosclerosis, the reflex measured from the involved ear does not register, because the stapes is incapable of movement, even though it is pulled by the stapedius tendon. In otosclerosis the acoustic impedance may be expected to be high and the compliance low.

20. Characteristic immittance results in patients with otosclerosis include _____ compliance and _____ acoustic reflexes.

Treatment of Otosclerosis. Interest in the surgical correction of otosclerosis dates back many years. Even in fairly recent times, surgical relief of otosclerotic hearing loss met with failure, primarily for two reasons. First, before the introduction of antibiotics, postoperative infection caused severe complications. Second, until the development of the operating microscope, middle-ear surgeons could not clearly see the very small operative field of the middle ear.

Because early attempts to free the immobilized stapes resulted in failure, often in the form of fractured crura, attention was turned to bypassing the ossicular chain. A new window was created in the lateral semicircular (balance) canal of the inner ear so that sound waves could pass directly from the external ear canal to the new window. This procedure was conducted as a two-stage operation until the one-stage **fenestration** was developed by Lempert (1938).

Fenestration surgery resulted in considerable hearing improvements for many patients with otosclerosis; however, it was recognized early that complete closure of the preoperative air-bone gap was impossible as a result of loss of the sound-transmission advantage of the tympanic

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AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐	RIGHT								LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000
Masking Type WB ☐ NB ☐	25	20	20	15	5	10	0	0	0	30	20	15	10	5	0	0	5	5
EM Level in Opp. Ear																		

BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT						FOREHEAD						LEFT					
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type WB ☐ NB ☒	0*	5*					-5	5	10	15	10	5	-5*	5*				
EM Level in Opp. Ear	40	20											25	20				

	2 Freq	3 Freq	Variable	WEBER							2 Freq	3 Freq	Variable
Pure Tone Average	13	15	15	M	M	M	M	M	M	Pure Tone Average	10	13	13

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☒	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
	20		List 15 HL 96%	List 15 HL 98*	15		List 15 HL 94%	List 15 HL 98*
EM Level in Opp. Ear				35				35

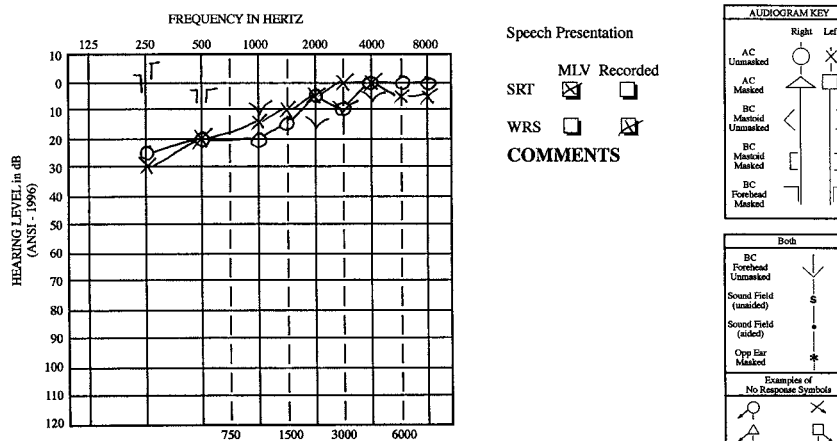


FIGURE 10.20 Audiogram illustrating early otosclerosis in both ears. The loss appears first in the low frequencies because of the increased stiffness of the ossicular chain. A small air-bone gap is present. Word-recognition scores are normal, and the Weber does not lateralize. Masking was used for bone conduction only at 250 and 500 Hz, and for word-recognition testing. Note the early appearance of the Carhart notch.

membrane and the ossicular chain. A 25 dB conductive component to the hearing loss usually remained following even the best fenestration. There were also many people who found no improvement in their hearing, and a number showed a considerable drop in their sensory/neural sensitivity. Some individuals with poor fenestration results even had total loss of hearing or were bothered by vertigo and increased tinnitus, as well as by poorer word-recognition scores and occasional facial paralysis. Hearing-aid use was sometimes obviated in the operated ear by a combination of poor speech discrimination and the large ear cavity created during surgery.

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AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐	RIGHT										LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000		
Masking Type WB ☐ NB ☐	45	50	40	40	35	40	40	35	50	50	50	45	40	40	40	45	45	40		
EM Level in Opp. Ear																				

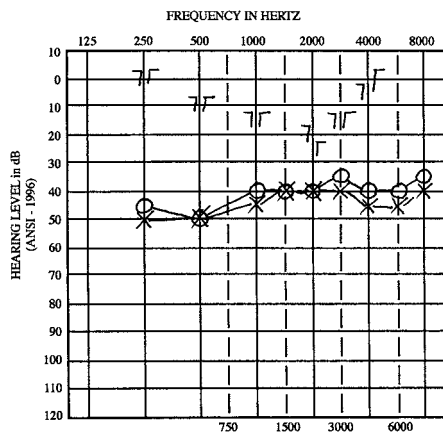
BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT						FOREHEAD						LEFT					
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type WB ☐ NB ☒	0*	10*	15*	20*	15*	5*	0	10	15	20	15	5	0*	10*	15*	25*	15*	0*
EM Level in Opp. Ear	50	50	45	40	40	45							45	50	40	50	35	50

	2 Freq	3 Freq	Variable	WEBER						2 Freq	3 Freq	Variable	
Pure Tone Average	40	43	43	M	M	M	M	M	M	Pure Tone Average	43	45	47

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☒	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
	45		List 96% HL	100*	45		List 96% HL	98*
EM Level in Opp. Ear			50	65			45	60



Speech Presentation

MLV Recorded ☒ ☐

SRT ☒ ☐

WRS ☐ ☒

COMMENTS

AUDIOGRAM KEY	
Right	Left
AC Unmasked	○
AC Masked	△
BC Unmasked	▽
BC Masked	□
Sound Field (unaided)	< >
Sound Field (aided)	[]
Opp Ear Masked	*
Both	
BC Forehead Unmasked	∇
Sound Field (unaided)	S
Sound Field (aided)	↑
Opp Ear Masked	*
Examples of No Response Symbols	
○	×
△	□

FIGURE 10.21 Audiogram showing a moderate loss of hearing in both ears caused by otosclerosis. The audiometric configuration is fairly flat, showing the combined effects of stiffness and mass. Bone conduction is normal except for the Carhart notch. Bone-conduction and WRS tests required masking.

Even if some patients were happy with the hearing results of their surgery, they were bothered by the constant aftercare required to clean the cavity.

While palpating a stapes on a patient preparatory to performing a fenestration, Rosen (1953) managed to mobilize the stapes, breaking it free and restoring the sound vibrations into the cochlea. This happenstance led to a completely new introduction, the **stapes mobilization** procedure.

Advantages of the mobilization over the fenestration were manifold. Patients could be operated on using local anesthesia, eliminating some of the side effects of general anesthesia.

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IMMITTANCE									
NAME Last - First - Middle				SEX	AGE	DATE	EXAMINER		INSTRUMENT
ACOUSTIC REFLEXES									
Frequency (Hz)	RIGHT				LEFT				
	500	1000	2000	4000	500	1000	2000	4000	
Ipsilateral (Probe same)		NR	NR			NR	NR		
Contralateral (Probe opposite)	NR	NR	NR	NR	NR	NR	NR	NR	
Audiometric Threshold									
Reflex SL									
Decay Time (Seconds)									

RIGHT					STATIC COMPLIANCE					LEFT				
Tymp. Width	M.E. Pressure	C Volume	C Compliance	C ₀ = C ₁ - C ₂	Tymp. Width	M.E. Pressure	C Volume	C Compliance	C ₀ = C ₁ - C ₂					
100	0	.62	.84	.22	100	0	.77	.95	.18					

TYMPANOGRAMS

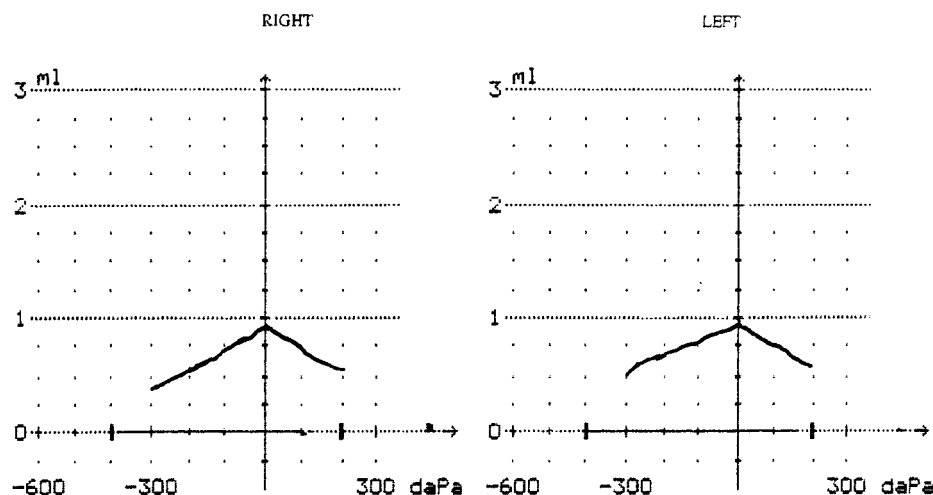


FIGURE 10.22 Results on immittance test performed on a patient with bilateral otosclerosis (Figure 10.21). The tympanogram is Type AS, the static compliance is low, and the acoustic reflexes are absent in both ears.

Because the ossicular chain remained intact, the patient's potential for postoperative hearing could be fairly well predicted by the preoperative bone conduction. Of great importance was the fact that no aftercare was required for mobilizations because no mastoid cavity was created during surgery.

In stapes mobilization, the ear canal is carefully cleansed and dried. The skin near the tympanic membrane is then anesthetized to deaden the area. A triangular incision is made in the skin, and the tympanic membrane reflected, exposing the middle ear. The surgeon then places a right-angle hook against the neck of the stapes, determines that it is fixed, and then rocks it until it is freed.

In spite of a number of variations of Rosen's operation, it was found that a great number of those patients whose hearing originally improved failed to retain this improvement after one year. The regression in hearing resulted from refixation of the stapes as new otosclerotic bone was laid down over the footplate. Refixation appears to be a greater problem for young patients, in whom the otosclerosis is more active, and for males.

Refixation following stapes mobilization led Shea (1958) to revive an operative procedure that had been described more than a half century earlier. This technique is called **stapedectomy**, which means "removal of the stapes," and is undoubtedly the procedure of choice for otosclerosis today.

21. The most popular surgery for correction of otosclerosis is _____.

The approaches to the middle ear for stapedectomy and mobilization are identical. After fixation has been determined, the incudostapedial joint is interrupted, the stapedius tendon is cut, and the superstructure of the stapes and remainder of the footplate are removed. In the original procedure, a vein graft, taken from the patient's hand or arm, was placed over the open oval window and draped on the promontory and over the facial ridge to obtain adequate blood supply. A hollow polyethylene strut was pulled onto the lenticular process of the incus, and the opposite end, which was beveled for a better fit, was placed in the oval window niche on the vein graft. In this way the polyethylene tube replaced the stapes.

In some cases, the polyethylene-with-vein procedure, though very popular, resulted in fistulas (leaks of inner-ear fluids into the middle ear), perhaps as a result of the sharp end of the strut resting on the vein. Testing for a **fistula** can be accomplished with the pressure portion of an immittance meter and an electronystagmograph (ENG) (see Chapter 11). Positive pressure is delivered to the middle ear by increasing the output of air pressure from the meter to 400 daPa. This may be accomplished regardless of whether a perforation of the tympanic membrane exists. If a fistula is present, the increased pressure within the middle ear may result in vertigo and an increase in rapid eye movement, called nystagmus, which can be monitored on the ENG.

In recent years a number of modifications of the original Shea stapedectomy have been introduced. Different materials have been used as the prosthesis: stainless steel wire, stainless steel pistons, Teflon pistons, combinations of steel and plastic, and so on. Some surgeons have used fat plugs from the tragus of the pinna and some **fascia** (the tough protective cover over muscle) to cover the oval window and support the prosthesis. Use of the patient's own tissue (autologous grafts) obviously works best in avoiding rejection. Although the success of stapedectomy has been substantial, and many patients with unsuccessful mobilizations have been reoperated with great improvements in hearing, some adverse reactions can and do occur, including further loss of hearing and prolonged vertigo.

To reduce risk in stapedectomy, many middle-ear surgeons today prefer to use a small fenestra and avoid the trauma to the inner ear of complete removal of the stapedia footplate. Small fenestra stapedectomies have been referred to as **stapedotomies** (Bailey & Graham, 1984). One such procedure is illustrated in Figures 10.23 to 10.28. After the ear has been locally anesthetized, and the tympanic membrane elevated from its sulcus, exposing the middle ear, the operation is begun. It should come as no surprise that there is a relationship between the experience of the surgeon and the success rates of stapedotomies. Experience plays a primary role in the two most delicate parts of the operation, which are the actual fenestration of the stapedia footplate and the crimping of the prosthesis onto the long process of the incus. As further modifications of the stapedectomy procedure continue to be perfected, such as the use of an argon laser, some form of stapedectomy will surely remain popular.

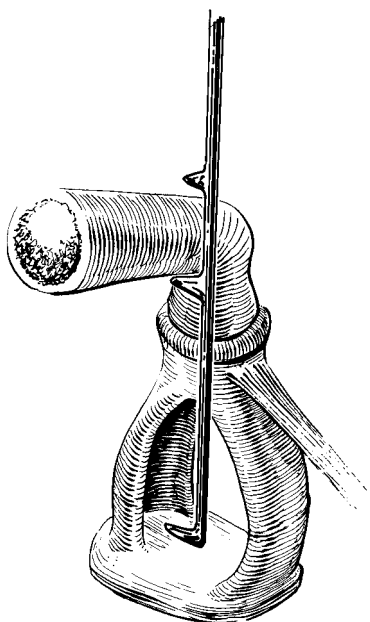


FIGURE 10.23 The proper length for the prosthesis is determined by measuring the distance from the undersurface of the incus to the footplate. A special measuring rod is used.

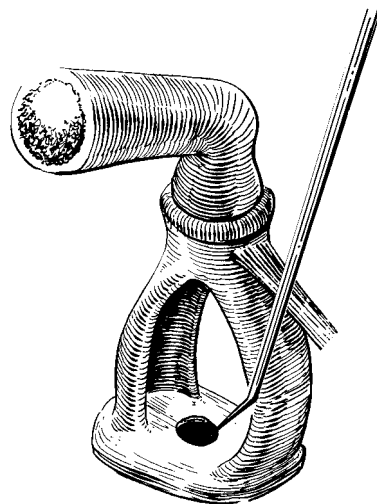


FIGURE 10.24 A small "control hole" is made in the center of the footplate; the hole is then enlarged with a pick or hand drill.

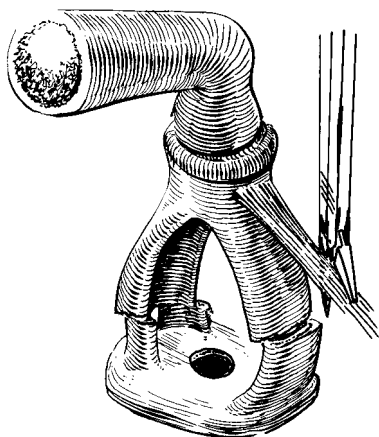


FIGURE 10.25 The crura are weakened and fractured, the incudostapedial joint is separated, and the stapedial tendon is severed with microscissors.

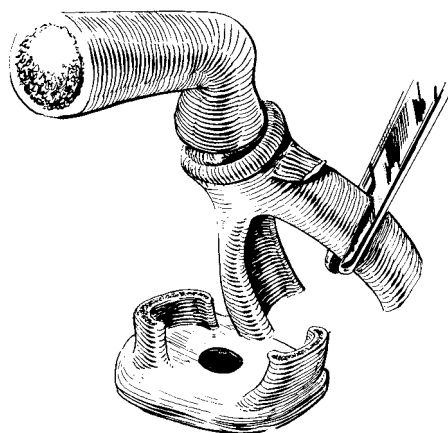


FIGURE 10.26 The superstructure of the stapes is removed.

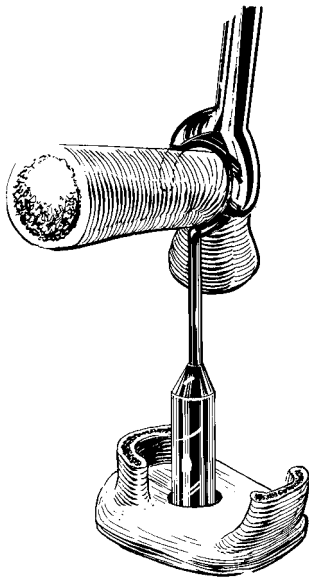


FIGURE 10.27 The prosthesis is carefully positioned, the wire hook is placed over the long process of the incus just above the lenticular process, and the hook is crimped snugly into position with a special crimping instrument.

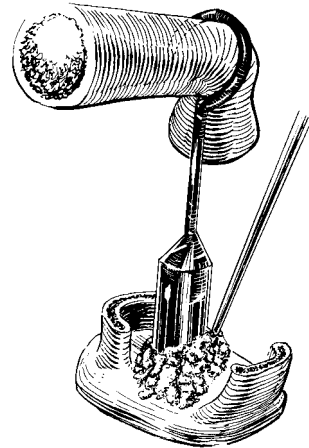


FIGURE 10.28 Superficial fascia from the temporalis muscle is placed around the end of the prosthesis, where it enters the footplate, to seal the inner ear. (Figures 10.23 through 10.28 courtesy of Arkansas Otolaryngology Center)

Other Causes of Middle-Ear Hearing Loss

Numbers of middle-ear abnormalities occur in isolation or in association with other congenital anomalies. Some cases of stapedial fixation appear purely on a genetic basis. A number of congenital middle-ear disorders were found in the offspring of mothers who took the drug thalidomide during pregnancy. Such conditions as fixation of the incudomalleal joint have been associated with atresias of the external auditory canal and microtias of the auricle. Other ossicular abnormalities have been associated with syndromes of the cheek, jaw, and face. Congenital malformations of the middle and outer ears are often seen together because these areas arise from the same embryonic tissue. Meyerhoff (1986) recommends delaying surgical repair in these situations until the child is 4 to 6 years old to permit the mastoid air-cell system to enlarge, allowing better surgical access.

Skull fractures have been known to result coincidentally in fractures or interruptions of the ossicular chain. Ossicular interruption has been reported in cases of skull trauma, even without fracture. An ossicle may also be damaged by a foreign object during traumatic perforation of the tympanic membrane, as with a cotton swab or bobby pin.

Tumors, both benign and malignant, may form in the middle ear. They may take the form of polyps, vascular tumors, and granulomas in response to middle-ear infections, or, in rare cases, cancer of the squamous cells of the middle ear.

EVOLVING CASE STUDIES

In this chapter we will look at the case that results in the diagnosis of otitis media. Consider the special diagnostic tests you might do and their probable results. In addition to pure-tone and speech audiometry, the basic workup should include immittance measures. It would probably not be necessary to perform otoacoustic emissions (OAE) or auditory brain-stem response (ABR), but it would be interesting to speculate about how those results would turn out.

Case Study 1: Conductive Hearing Loss

You have already been advised that audiometric findings for this patient would be comparable to what is observed in Figure 4.13. A typical, similar example in this chapter is shown in Figure 10.11. Note that there is a moderate hearing loss by air conduction for both ears and the bone-conduction thresholds are normal. Speech audiometry shows good agreement between the pure-tone averages and the SRTs, and the speech-recognition scores are high. These tests confirm the diagnosis of conductive hearing loss in both ears but do not indicate the etiology (origin) of the hearing loss, or the part of the auditory system that is involved. The history of ear infections suggests this as the cause, but this awaits further support by further testing.

Since the otologist reports that the tympanic membranes are intact, immittance measures (and your otoscopic examination) should confirm this. If it turns out that a seal cannot be obtained for immittance testing, the possibility of perforation should be re-explored. A retracted tympanic membrane would result in a tympanogram Type C (see the left ear in Figure 10.10). If there is fluid in the middle ear, the tympanogram will be fairly flat, which is a Type B (Figure 10.12). Since this is a long-standing problem, it is possible that the incus in one or both ears may be eroded, which would cause a Type A_D (see the right ear in Figure 10.19). Any of these etiologies would result in the loss of all acoustic reflexes.

If OAE and ABR testing were completed, there would almost certainly be no OAEs present. ABR findings would show a delay of all waves, as demonstrated in Figure 10.13. In cases such as this, medical reversal of the hearing loss is always the first avenue considered. A variety of such procedures is described in this chapter. Failing improvement in hearing, the rehabilitation will be of an audiological nature and is discussed further in Chapter 15.

Summary

The middle ear is an air-filled space separating the external auditory canal from the inner ear. Its function is to increase sound energy through leverage, the step-down size ratio provided by the ossicular chain, and the area ratio between the tympanic membrane and the oval window.

Abnormalities of the structure or function of the middle ear result in conductive hearing losses, wherein the air-conduction thresholds are depressed in direct relationship with the amount of disease. Bone-conduction thresholds may deviate slightly from normal in conductive hearing losses, not because of abnormality of the sensory/neural mechanism, but because of alterations in the middle ear's normal (inertial) contribution to bone conduction. Alterations in the pressure-compliance functions give general information regarding the presence of fluid or negative air pressure in the middle ear, stiffness, or interruption of the ossicular chain. Measurements of static compliance may be higher or lower than normal, and acoustic reflex

thresholds are either elevated or absent. Auditory brain-stem responses show increased latencies for all waves and otoacoustic emissions are usually absent. Results on word-recognition tests are the same as for those with normal hearing. Although seldom completed today, results of the behavioral site-of-lesion tests discussed in Chapter 7, such as SISI, ABLB, and tone-decay, would also be the same as those with normal hearing.

Remediation of middle-ear disorders should first be concerned with medical or surgical reversal of the problems. When this fails, must be postponed, or is not available, careful audiological counseling should be undertaken, and treatment avenues, such as the use of hearing aids, investigated. Provided they have no medical contraindications to hearing-aid use and no planned medical or surgical intervention, patients with conductive hearing losses are excellent candidates for hearing aids because of their relatively flat audiometric contours, good word recognition, and tolerance for loud sounds.

REVIEW TABLE 10.1 Conductive Hearing Loss in the Middle Ear

<i>Etiology</i>	<i>Degree of Loss</i>	<i>Audiometric Configuration</i>	<i>Static Compliance</i>	<i>Tympanogram Type</i>
Suppurative otitis media	Mild-to-moderately severe	Flat	Normal to low	B
Tympanic membrane perforation	Mild	Flat	Not testable Large equivalent volume	Not testable
Ossicular chain discontinuity	Moderate	Flat	High	A _D
Serous effusion	Mild-to-moderate	Flat or poorer in high frequencies	Normal-to-low	B
Negative middle-ear pressure	Mild	Flat	Normal	C
Otosclerosis	Mild-to-moderately severe	Flat or poorer in low frequencies	Low	A _S
Congenital disorders	Mild-to-moderately severe	Varies	Varies	Varies

Related Website

www.bris.ac.uk/Depts/ENT/otoscopy_tutorial.htm

This website provides an endoscopic view of a variety of otologic conditions as they appear at the tympanic membrane including TM perforations, tympanosclerosis,

cholesteatoma, hemotympanum, and others. Additional color photos of otopathologies are provided on the text's Companion Website.

Study Questions

1. List as many parts of the middle ear as you can. Consider their functions. Compare your list to the diagram of the ear in Figure 10.1.
2. Make a list of disorders of the middle ear that produce conductive hearing loss. Next to each item, name an appropriate treatment.
3. For each of the disorders just listed, sketch a pure-tone audiogram. What would the probable results be on the following tests: SRT, speech-recognition, acoustic immittance, ABR, OAE, and tone-decay?

Suggested Readings

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Endnotes

1. For Bartolommeo Eustachio, sixteenth-century Italian anatomist.
2. For Adam Politzer, Hungarian Otologist, 1835–1920.
3. For Antonio Maria Valsalva, Italian anatomist, 1666–1723.
4. For Joseph Toynbee, British otologist, 1815–1866.
5. For Sir Charles Bell, Scottish physiologist, 1774–1842.

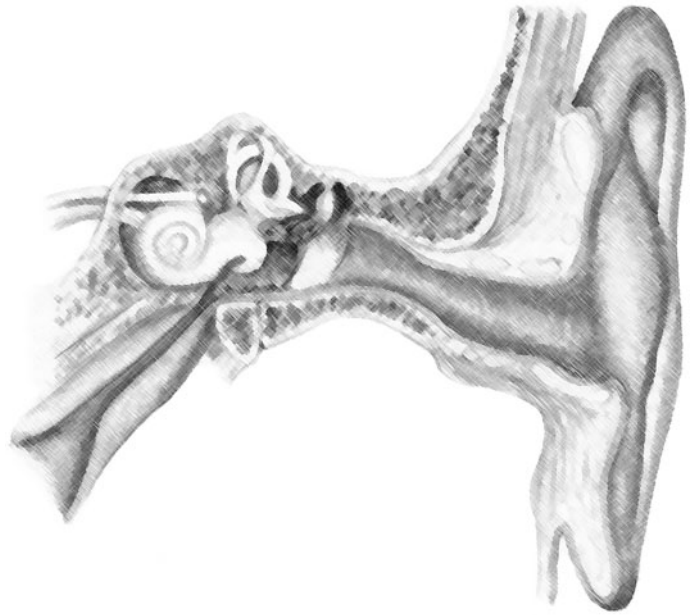
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CHAPTER 11

The Inner Ear



SINCE THE ANIMAL BRAIN cannot use sound vibrations in the form as described in Chapter 3, the function of the inner ear is to **transduce** the mechanical energy delivered from the middle ear into a form of energy that can be interpreted by the brain. In addition to information about hearing, the inner ear also reports information regarding the body's position and movement in a bioelectrical code. The inner ear is extremely complicated, with literally thousands of moving parts, but it is so tiny that it has been compared to the size of a small pea. Because of its similarity to an intricately winding cave, the inner ear has been called a **labyrinth**.

LEARNING OBJECTIVES

This chapter describes the inner ear as a device that provides the brain with information about sound and the body's position in space. Once this chapter has been completed, the reader should be able to

- Identify the anatomical landmarks of the inner-ear mechanism.
- Briefly describe the contributions of the inner ear to hearing and spatial orientation.
- List a variety of disorders that affect the inner-ear and give their causes, stating if they would be prenatal, perinatal, or postnatal in origin.
- Discuss the probable results on auditory tests described earlier in this book as they may relate to inner-ear disorders.

Anatomy and Physiology of the Inner Ear

The footplate of the stapes fits neatly into the oval window, so called because of its shape. The oval window is the separation between the middle ear and the inner ear. The immediate entryway is called the **vestibule**; it is an area through which access may be gained to various chambers of the inner ear, just as the vestibule in a house is a space that may communicate with several different rooms. The vestibule is filled with a fluid called **perilymph**. It is within the vestibular portion of the inner ear that the organs of equilibrium are housed. The connections between the balance (vestibular) and auditory (cochlear) portions of the inner ear are considered separately here for ease of learning, but they are intricately connected both anatomically and physiologically (Figure 11.1).

The Vestibular Mechanism

As in many animals, the human ability to maintain balance depends on information from several body systems, interactions among which are controlled in the **cerebellum**. These systems include visual, proprioceptive, and vestibular input. The visual system provides direct information from surrounding objects on the orientation of the body and depends on the ability of the eyes to see and the presence of sufficient light to make surroundings visible. Proprioception concerns **somatosensory** stimuli received in tissue from supporting structures, such as the muscles and tendons of the body. These stimuli allow the perception of body-part positioning. The vestibular system relies on the forces of gravity and inertia.

Within the vestibule are membranous sacs called the **utricle** and the **sacculle**. Both sacs are surrounded by perilymph and contain another fluid, very similar in constitution, called **endolymph**. The sacculle is slightly smaller than the utricle. The end organ for balance within the utricle (*macula acoustica utriculi*) is located at the bottom, and the end organ within the sacculle (*macula acoustica sacculi*) is located on the side.

Arising from the utricle are the superior, lateral, and posterior **semicircular canals**, which are also membranous, containing endolymph, and surrounded in a larger bony cavern by perilymph. Each of the three canals returns to the utricle through enlarged areas called **ampullae**. Each **ampulla** contains an end organ (*crista*) that provides a sense of equilibrium. The semicircular canals are arranged perpendicularly to one another to cover all dimensions in space. With any angular acceleration, at least one semicircular canal is stimulated.

1. Two fluids found within the inner ear are _____ and _____.

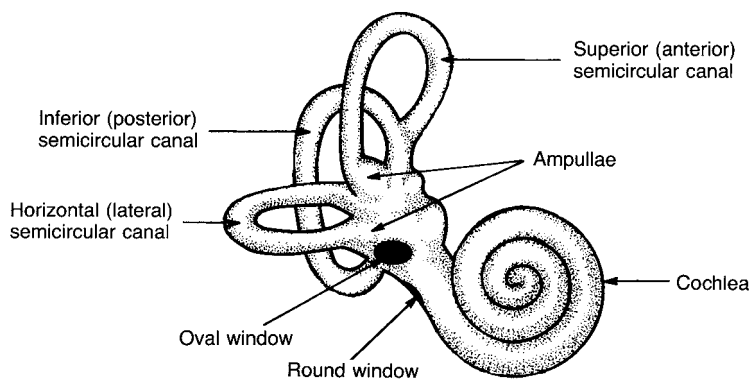


FIGURE 11.1 Anatomy of the human inner ear.

1. perilymph, endolymph

When the head is moved, the fluids in the vestibule tend to lag behind because of their inertia. In this way the fluids are set into motion, which stimulates the vestibular mechanism. The utriculosaccular mechanism is responsible for interpreting *linear acceleration*, and it is through this mechanism that we perceive when an elevator or automobile is picking up speed or slowing down. The utricle and saccule are stimulated by the rate of change of linear velocity, which can be measured in centimeters per second squared. The semicircular canals are the receptors for *angular acceleration*, or the rate of change of angular velocity. These receptors report, for example, the increase or decrease in the number of revolutions per minute that the body is turning. Thus, angular acceleration can be measured in degrees per second squared.

2. Disturbance of the vestibular mechanism often results in the sensation of true turning called _____. It is associated with rapid eye movements called _____.

When vestibular mechanisms become damaged or diseased, a common symptom called **vertigo** results. Patients with vertigo are truly ill because they experience the sensation of whirling or spinning. Because of connections in the brain between the vestibular portion of the auditory nerve and the oculomotor nerve, a rapid rocking movement of the eyes, called **nystagmus**, frequently occurs. Nystagmus always comes about with vertigo, regardless of whether one can see it, and it may occur spontaneously in cases of vestibular upset. It is important to differentiate true vertigo from dizziness, light-headedness, or falling tendencies, which do not result in the sensation of true turning.

Tests for Vestibular Abnormality. For some time, attempts to determine the normality of the vestibular system have centered on artificial stimulation. In one test the patient is placed in a chair capable of mechanically controlled rotation. Following a period of rotation, the eyes are examined for nystagmus. The presence, degree, and type of nystagmus are compared to the examiner's concept of "normal."

A considerably easier test to administer in the otologist's or audiologist's office is the **caloric test**. Stimulation of the labyrinth is accomplished by "washing" cold or warm water or air against the tympanic membrane, with temperatures actually varying only slightly below or above normal body temperatures. In patients with normal vestibular systems, the result when cold water or air is used is a nystagmus with rapid movement away from the irrigated ear and slow movement back. When warm water or air is used, the direction of nystagmus is reversed. The acronym COWS (cold-opposite, warm-same) is a useful mnemonic. Interpretations of responses as normal, absent, hyperactive, or hypoactive are highly subjective and vary considerably among administrators of this test.

There is a difference in electrical potential between the cornea (positive charge) and the retina (negative charge) of the eye. Knowledge of this fact led to the development of a device called the **electronystagmograph (ENG)** to measure the changes in potential produced by nystagmus and to increase the objectivity of vestibular testing. This equipment allows for measurement of the rate and direction of nystagmus, which can be displayed on a paper chart as a permanent recording or exhibited on a computer terminal and saved and/or printed. Most commercial ENGs heat and cool the water for irrigation to precise temperatures (30° and 44°C) and eject the proper amount (250 milliliters) over a prescribed period of time (40 seconds). A slightly longer irrigation is required for air calorics. All this automaticity has considerable advantage over manual methods of testing, but most important is the fact that a permanent and accurate result is available. The use of microcomputers in vestibulography allows for better quantification of the eyebeats resulting from caloric testing through better control of the stimuli and resolution of the responses. A variety of tests is currently available, and software is constantly being upgraded. Computers have allowed for the reintroduction of **rotary chairs** as a means of assessing the functions of the vestibular system, including those of children.

3. The ENG has increased the objective measure of nystagmus. In particular, the ENG determines the _____ and _____ of nystagmus.



FIGURE 11.2 Specialized goggles allow for the observation and video recording of eye movement while testing the dizzy patient or while performing vestibular rehabilitation. (Courtesy of Micromedical Technologies, 10 Kemp Drive, Chatham, IL 62629)

The use of strategically placed electrodes around the eyes for measurement of electrical potential changes in eye movement—with their calibration, physiologic noise, and other problems—has largely been replaced with an infrared video system that uses tiny cameras to track eye movements in response to vestibular tests (Figure 11.2). The area inside the goggles is dark, allowing patients to keep their eyes open during testing, as the infrared light is invisible to them. The absence of electrodes makes testing easier and eye movements can be viewed on a video monitor or videotaped for later review.

Before the advent of computerized vestibulography, ENG testing on infants and small children was difficult, if not impossible. Cyr and Møller (1988) recommend that children be tested for vestibular dysfunction if (1) they show delayed or abnormal motor function, (2) they take ototoxic medications, (3) they have a spontaneous nystagmus, or (4) there is suspected neurological disease. It would probably be advisable to carry out vestibular testing on children with sensory/neural hearing loss whenever possible because many of them apparently suffer from significant vestibular abnormalities (Brookhouser, Cyr, & Beauchaine, 1982).

Until recently, vestibulography was limited to the vestibulo-ocular reflexes, the connections between the balance and visual systems in the brain. There are new pursuits of other central nervous system interactions, including **computerized dynamic posturography (CDP)**, that assess the ability to coordinate movement by measuring vestibulospinal reflexes. Many of the tests now available are directly related to the introduction of computers to the measurement of vestibular function. While measuring patients' postural compensations as the platform on which they are standing is rotated at various angles, CDP provides a quantitative assessment of upright balance through simulation of conditions encountered in daily life (Figure 11.3). By isolating the sensory, motor, and biochemical components that contribute to balance, CDP analyzes a patient's ability to use these components individually and in combination to maintain balance.

FIGURE 11.3 Computerized dynamic posturography provides a quantitative assessment of upright balance by measuring postural compensations as the platform on which a patient stands is rotated at various angles. (Courtesy of Neurocom® International, Inc.)



While some of the test protocols within CDP provide insights on a patient's functional capacity for a variety of daily life tasks, others help to localize the cause of a balance disorder (Nashner, 1993). CDP test results can aid in the diagnosis of specific underlying disease processes.

The **vestibular-evoked myogenic potential (VEMP)** can also shed light on the status of a patient's vestibular system. The VEMP is a **sound-evoked muscle reflex** believed to be generated from acoustical stimulation of the saccule, one of the vestibular end organs that sense linear acceleration. The purpose of this reflex may be to stabilize the head in response to unpredictable movements. Measured through evoked-potential techniques, the response may be recorded from a variety of muscles, including the **trapezius** or **sternocleidomastoid muscles**, when an acoustic stimulus is presented to one ear while the patient sharply turns his or her head in the direction opposite the stimulated ear. Asymmetries in response between the two sides of the head may shed clinical insights into cases of perilymphatic fistula (a pathologic communication between the normally fluid-filled inner ear and the air-filled middle ear typically at either the oval or round window) or patients who yield normal results on conventional measures of peripheral vestibular function, such as caloric or rotary-chair tests, yet report abnormal sensations of linear acceleration.

Computerized dynamic posturography, vestibulography, and vestibular-evoked myogenic potentials are lending innovative and exciting aspects to the diagnosis of diseases of the inner ear and central nervous system. However, balance function tests must be considered along with the medical history, medical examination, and audiometric findings, and the extent to which audiologists should be clinically involved in such procedures continues to be debated.

Clinical Commentary

The assessment of vestibular disorders has become a major component of many audiologists' professional responsibilities. As discussed in Chapter 14, more recently audiologists have expanded the services they provide to encompass rehabilitative interventions for the balance problems of their patients.

The Auditory Mechanism

The vestibular portions of the inner ear were shown in Figure 11.1, along with the auditory portions. Notice that the vestibule, the area just past the oval window, also communicates with a snail-like shell called the **cochlea**. For clarification, teachers are fond of “unrolling” the cochlea (Figure 11.4), an act that is graphically advantageous but physically impossible because the cochlea is made up of a twisting bony shell about 1 cm wide and 5 mm from base to apex in humans.

Beyond the oval window within the cochlea lies the **scala vestibuli**, so named because of its proximity to the vestibule and its resemblance to a long hall. At the bottom of the cochlea the **scala tympani** is visible, beginning at the round window. Both of these canals contain perilymph, which is continuous through a small passageway at the apex of the cochlea called the **helicotrema**. For frequencies above about 60 Hz, there is little fluid movement through the helicotrema, as energy is transmitted through the fluids of the cochlea by the movement of the membranes.

Between the two canals just described lies the **scala media**, or **cochlear duct**. This third canal is filled with endolymph, which is continuous through the **ductus reuniens** with the endolymph contained in the saccule, utricle, and semicircular canals. The scala media is separated from the scala vestibuli by **Reissner's membrane**¹ and from the scala tympani by the **basilar membrane**. When the cochlea, which curls about two and a half turns, is seen from the middle ear, the large turn at the base forms the protrusion into the middle ear called the **promontory**.

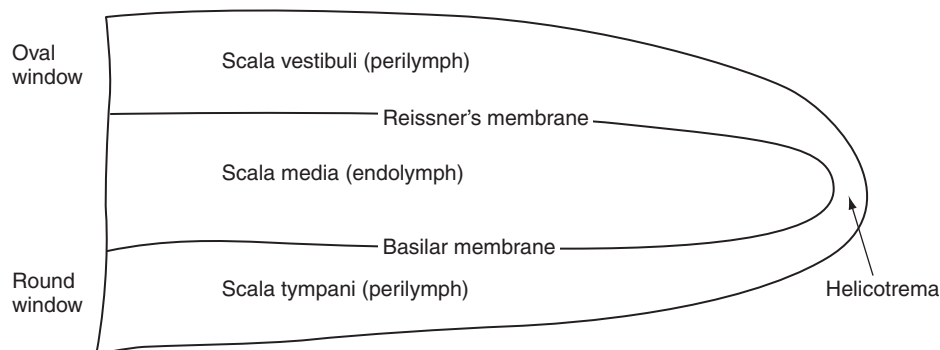


FIGURE 11.4 Diagram of an “unrolled” cochlea, showing the relationships among the three scalae.

4. The portion of the inner ear responsible for equilibrium is called the _____, and the portion responsible for hearing is called the _____.

5. The three fluid-containing channels of the inner ear are the _____, _____, and _____.

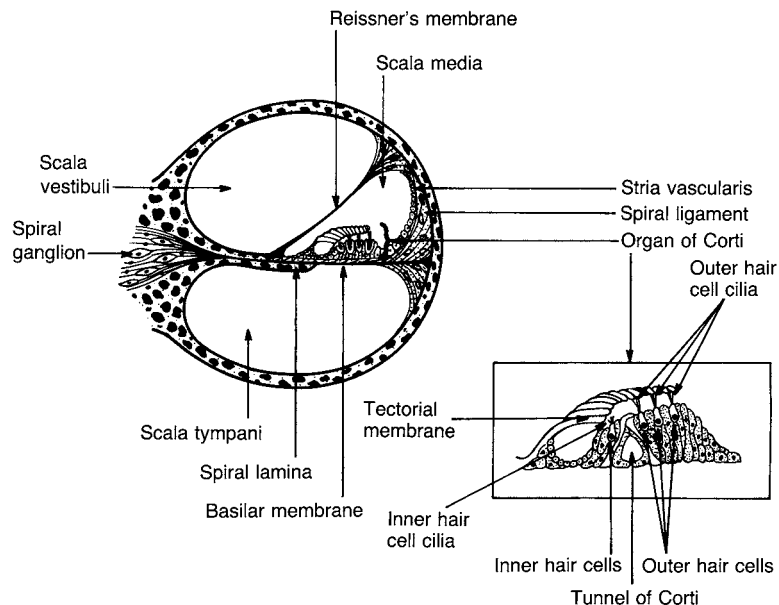


FIGURE 11.5 Cross section of the cochlea.

Along the full length of the scala media lies the end organ of hearing, the **organ of Corti**², which resides on the basilar membrane, one of the three walls of the scala media. The other two walls are made up of Reissner's membrane and a bony shelf formed by a portion of the bony labyrinth. From this shelf extends the **spiral ligament**, support for the scala media, and also the **stria vascularis**, which produces the endolymph and supplies oxygen and other nutrients to the cochlea. The blood supply and nerve supply enter the organ of Corti by way of the **modiolus**, the central core of the cochlea around which it is wound. A cross section of the cochlea is shown in Figure 11.5. Much of what is known of the anatomy and physiology of the inner ear has been advanced in recent years with the introduction of electron microscopy.



A variety of schemata of the inner-ear mechanism may be found under "Anatomy" in the Learning Supplements section of the Companion Website.

Basilar Membrane

The basilar membrane is about 35 mm long and varies in width from less than 0.1 mm at the basal turn to about 0.5 mm at the apical turn, quite the reverse of the cochlear duct, which is broad at the basal end and narrow at the apex. Situated on the fibrous basilar membrane are three to five parallel rows of 12,000 to 15,000 outer hair cells and one row of 3,000 inner hair cells. The outer and inner hair cells are separated from each other by **Corti's arch**. The auditory nerve endings are located on the basilar membrane. Some of these nerve fibers connect to the hair cells in a one-to-one relationship, while others make contact with many hair cells. The hair cells themselves are about 0.01 mm

6. The basilar membrane supports the _____, while Reissner's membrane separates the scala vestibuli from the _____.

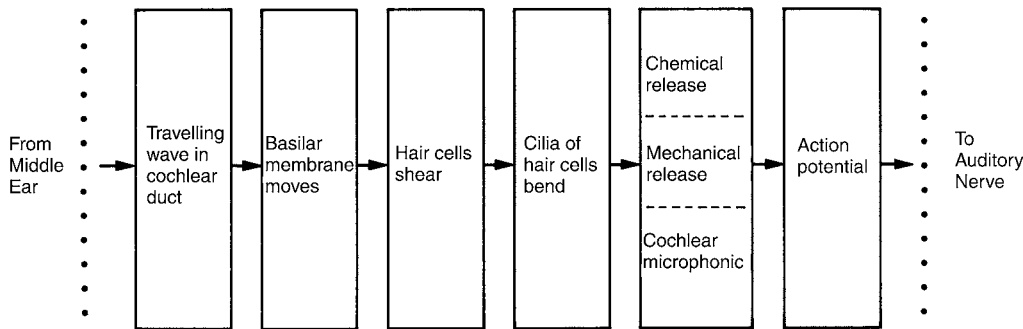


FIGURE 11.6 The functions of the cochlea.

long and 0.001 mm in diameter. Located on top of each hair cell are hair-like projections called **stereocilia**. The direction in which they are bent during stimulation is of great importance. If the cilia bend in one direction, the nerve cells are stimulated; if they bend the other way, the nerve impulses are inhibited; and if they bend to the side, there is no stimulation at all. A flow diagram showing a model of cochlear function is shown in Figure 11.6.

Physiology of the Cochlea

When the oval window is moved in by the stapes, the annular ligament around the footplate stretches and displaces the perilymph at the basal end of the cochlea, propagating a wave toward the apex of the cochlea. Because the fluids of the inner ear are noncompressible, when they are inwardly displaced at the oval window, the round window membrane must yield, moving into the middle ear. It may be said, therefore, that the two windows are out of phase. It is obvious that if they were in phase, a great deal of cancellation of sound waves would take place within the cochlea, just the opposite of the desired effect.

Sound vibrations that are introduced to the scala vestibuli are conducted into the cochlear duct by the yielding of Reissner's membrane. The endolymph is thereby disturbed, so the vibrations continue and the basilar membrane is similarly displaced, resulting in the release of the round window membrane. Therefore, sounds introduced to the inner ear cause a wavelike motion, which always moves from the base of the cochlea to the apex. This is true of both air- and bone-conducted sounds. Given areas along the basilar membrane show greater displacement for some frequencies than for others. Tones of low frequency with longer wavelengths show maximum displacement near the apical end, whereas tones of high frequency with shorter wavelengths show maximum displacement near the basal end.

The basilar membrane reacts more to vibrations of the inner ear than do most of the other structures. Because the organ of Corti resides on this membrane, the vibrations are readily transmitted to it. The stereocilia on the tips of the outer hair cells are embedded in the **tectorial membrane**, a gelatinous flap that is fixed on its inner edge and, according to some researchers, on its outer edge as well. When the basilar membrane moves up and down in response to fluid displacement caused by the in-and-out movement of the stapes, the hair cells are sheared (twisted) in a complex manner. Part of this shearing is facilitated by the fact that the basilar membrane and the tectorial membrane have slightly different axes of rotation and slide in opposite directions as they are moved up and down.

The three rows of outer hair cells are responsible for “sharpening” the fluid-borne wave within the cochlea, thereby enhancing frequency discrimination. Outer-hair cell damage, which occurs in many cochlear hearing losses, reduces this sharpening with a resultant decrease in speech-recognition abilities, especially in background noise. The outer-hair cells also enhance the reception of sound by the inner hair cells by shortening themselves thereby bringing the inner hair cells into contact with the tectorial membrane. Without this assistance from the outer hair cells, the inner hair cells are limited to stimulation from the motion of the endolymphatic fluid within the scala media responding only to sounds above about 40 to 60 dB SPL. Hearing loss below these levels would be attributed primarily to outer-hair cell damage. Greater degrees of hearing loss would imply damage to both the outer and inner hair cells.

The mechanics of the organ of Corti are very complex, resulting from motion of the basilar membrane in directions up and down, side-to-side, and lengthwise as well as an active motility of the outer hair cells. The size of electrical response of the cochlea is directly related to the extent to which the hair cells, or the ciliary projections at their tops, are sheared. The source of the electrical charge is derived from within the hair cell. When the cilia are sheared, a chemical is released at the base of the hair cell.

Each inner hair cell of the cochlea is supplied by about 20 nerve fibers, each nerve fiber contacting only one hair cell. This is not true of the outer hair cells, where the neuron-to-hair cell ratio is 1:10. Each outer hair cell may be innervated by many different nerve fibers, and a given nerve fiber goes to several outer hair cells. The nerve fibers exit the cochlea and extend centrally toward the modiolus, where their cell bodies group together to form the spiral ganglion. The nerve fibers pass from the modiolus to form the cochlear branch of the auditory (VIIIth cranial) nerve.

The Auditory Neuron

The human cochlea contains about 30,000 afferent (sensory) **neurons** and about 1800 efferent neurons. A neuron is a specialized cell designed as a conductor of nerve impulses. It is comprised of a **cell body**, an **axon**, and **dendrites** (Figure 11.7). The axon and dendrites are branching systems. The dendrites, which consist of many small branches, receive nerve impulses from other nerve

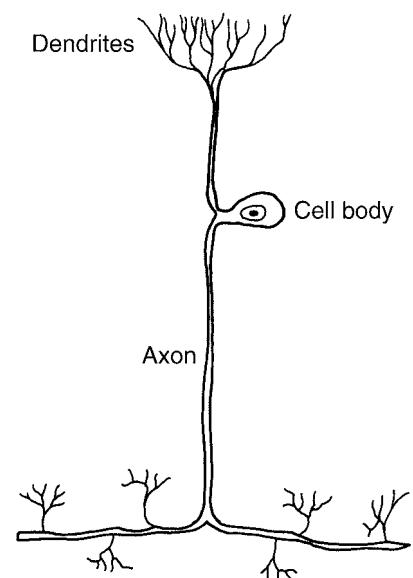


FIGURE 11.7 Diagram of a bipolar sensory neuron, such as are seen in the cochlea.

cells. The axon transmits the impulses along the neurons, which vary dramatically in length. The afferent neurons carry impulses from the cochlea to the central auditory nervous system and have their cell bodies in the spiral ganglion in the modiolus. As Figure 11.7 shows, auditory neurons are bipolar, in this case having one dendritic projection to the hair cells and another axon projecting to the sensory cells in the brain stem. The efferent axons project from the superior olivary complex in the brain stem and contact the hair cells both directly and indirectly.

Electrical impulses travel along the entire length of the axon. The stimulus is received by the dendrites, which conduct it to the cell body and then to the axon. The electrical power of the neuron is derived from the axon, which generates its voltage chemically from its surroundings. Connections between neurons are called **synapses**. Once the electrochemical threshold has been reached, a neuron always responds with its maximum charge, regardless of the stimulus intensity. This has been called the *all-or-none* principle.

The act of conveying information between neurons is called **neurotransmission**. At one end of each nerve cell connections are made with other nerve cells, either through their dendrites or directly with their cell bodies. Chemical substances, called **neurotransmitters**, that cause activation or inhibition of adjacent neurons are released at these junctions.

7. Once a neuron's threshold has been reached, it fires with its maximum charge, a phenomenon known as the _____.

The Fluids of the Cochlea

Although similar, the constituents of the perilymph and endolymph are different in ways essential to the physiology of hearing. Endolymph is high in its concentration of potassium ions and low in sodium, whereas the reverse is true of perilymph. Another way in which the two fluids are dissimilar is in their DC (direct current) potentials (voltages). Endolymph exhibits a strong positive potential, averaging about 80 millivolts (mV), caused by its high potassium concentration, compared to the perilymph of the scala tympani. The perilymph in the scala vestibuli demonstrates a positive, but much smaller, potential of about 3 mV when compared to the perilymph of the scala tympani. The remainder of the cochlear structures exhibits a negative DC potential. All of these potentials fluctuate.

The Cochlear Microphonic

The cochlea is the transducer that converts sound waves into an energy form useful to the auditory nerve. Because of its resemblance to the action of a microphone, which converts the pressure waves issuing from a speaker's mouth into an alternating electrical current, this action has been named the **cochlear microphonic (CM)**. The cochlear microphonic is probably the result of changes in polarization caused by the bending back and forth of the hair cell cilia. For every up-and-down cycle of the basilar membrane, there is one in-and-out cycle of the stereocilia of the outer hair cells, causing them to become alternately depolarized and hyperpolarized. The size of the cochlear microphonic has been measured by placing pickup electrodes over the round window and, in some cases, within the cochlea.

The Action Potential

At the moment that auditory neurons are stimulated by the hair cells that rest on them, a change in the electrical potential occurs on the surface of each neuron. This is called the **action potential (AP)**. Increases in the intensity of the auditory input signal to the cochlea result in increased electrical

output from the hair cells. This stimulation causes increased electrical activity in the neuron, although each individual neuron continues to follow the all-or-none rule.

The Efferent System of the Cochlea

8. Afferent neurons transmit impulses _____ the cochlea, while efferent neurons transmit impulses _____ the cochlea.

We tend to think of our sensory systems as being entirely **afferent**, carrying messages only from the sense organs, like the ear, to the brain for analysis. However, it is clear that the cochlea contains an efficient **efferent** system, receiving impulses from the brain. The relationship between afferent and efferent fibers is delicately balanced to provide a feedback, or monitoring, system for the cochlea.

Theories of Hearing

To this day, the precise means by which we hear remains unknown, although underlying mysteries continue to be resolved. Early theories that attempted to explain how the ear utilizes the mechanical energy delivered to the cochlea from the middle ear were largely theories of how we perceive pitch.

Helmholtz's³ **resonance theory of hearing** stated that the structures within the cochlea consist of many tiny resonators, each tuned to a specific frequency. While his notions of hearing have since been disproved, he was the first to describe the placement of the higher-frequency fibers at the basal end of the cochlea and the lower frequencies near the apex.

A logical early belief was that every tone that could be heard was assigned to its own specific place within the cochlea, much as the keys of a piano are laid out with specific pitch representation. This **place theory of hearing** begins to break down when it attempts to explain why pitch discrimination is so poor close to auditory threshold, although its consideration as an incomplete theory of pitch perception may be viable.

While the place theories attributed analysis of pitch to the cochlea, several frequency-based theories, including the **volley theory of hearing** and the **resonance-volley theory**, attempted to place this analysis in a **retrocochlear** area. It was not until the mid 20th century that Békésy⁴ (1960) described what he called the **traveling wave theory**, which put forth the explanation recognized today as the basis for cochlear pitch perception.

The traveling wave theory explains that for each inward and outward movement of the footplate of the stapes, there is a downward and upward movement of the basilar membrane, produced by disturbance of the endolymph. The wave moves down the cochlear duct from base to apex, with the maximum amplitude for high-frequency tones occurring at the basal end and that for the low frequencies at the apical end, with the outer hair cells functioning to sharpen the wave for greater frequency discrimination. Although high frequencies excite only the fibers in the basal turn of the cochlea, the low frequencies excite fibers all along the basilar membrane. The input frequency, then, determines not only the distance the traveling wave moves before it peaks, but also the rate of basilar membrane vibration. The frequency of basilar membrane vibration is directly related to frequency and inversely related to period.

The place theories, including the traveling wave theory, explain loudness in terms of the amplitude of movement of the basilar membrane; that is, a louder sound creates greater amplitude of basilar membrane movement than a softer sound. This greater amplitude increases the number of impulses transmitted by the nerve fibers. The frequency theories explain loudness in terms of the amount of spread along the basilar membrane. The greater the amplitude

of the input signal, the larger the surface area of the basilar membrane stimulated, and the greater the number of nerve fibers firing, both at the peak of the traveling wave and on both sides of it. Although intensity coding is extremely complicated and poorly understood, it is generally agreed that as the intensity of a signal is increased, neurons in the brain stem fire at higher rates, resulting in greater loudness of the signal.

Hypotheses for Hair Cell Transduction

It is still not entirely understood how the mechanical motion of the hair cells (shearing) converts a sound source into a form of energy that can be transmitted by the auditory nerve. The *mechanical hypothesis* assumes that the pressure that moves the hair cells stimulates the nerve endings directly. The *chemical hypothesis* assumes that when the hair cells are deformed, a neurotransmitter substance is released that stimulates the nerve endings. The *electrical hypothesis* assumes that the cochlear potential stimulates the nerve endings. The conversion of acoustic energy into a neural impulse is a combination of an electrochemical response to the mechanical motion of the hair cells in the inner ear.

Otoacoustic Emissions

A great deal of thinking about the way the inner ear works has changed because of the remarkable discovery by Kemp (1978) that the cochlea, previously believed to be an organ that responds only to sounds entering the inner ear from the middle ear, in fact, generates sounds of its own. Acoustic emissions had been observed in previous research, but were ignored and considered to be experimental artifacts. What Kemp discovered, through miniature microphones sealed in the external ear canals of human subjects, was an actual, weak acoustic signal, probably generated by the motility of the outer hair cells. The discovery now allows for study of these **otoacoustic emissions (OAEs)** in the cochlear function in humans and animals alike (Allen & Lonsbury-Martin, 1993) and adds credence to the theory of the cochlear amplifier.

Spontaneous otoacoustic emissions (SOAEs), which can be detected without external stimulation, occur in 40 to 60% of normal ears (DeVries & Decker, 1992; Probst, Lonsbury-Martin, & Martin, 1991). In some cases they are audible to the subjects themselves at very low sensation levels. SOAEs may be understood on the basis of several generally accepted facts about the cochlea, specifically that the normal cochlea is very sharply tuned and processes sound nonlinearly. Damage to outer hair cells usually causes the emission to disappear.

Outer hair cell movement appears to generate waves that are conducted along the basilar membrane, through the intracochlear fluids, toward the basal end of the cochlea, then via the ossicular chain to the tympanic membrane, which acts as a loudspeaker in delivering a weak sound into the external auditory canal. It is known that the emissions are present in one or both ears of some humans (more often in right ears than in left ears, and more often in females than in males), but not of others, and that they are often absent in people with cochlear hearing loss. Any conductive hearing loss will attenuate the intensity of the sound traveling outward from the cochlea and will generally make the emissions unrecordable.

Hypotheses that the phenomenon of OAEs arises from something other than a cochlear event (such as a muscular contraction or a sound generated in the middle ear) have been systematically eliminated. The relationship between these emissions and cochlear

9. Spontaneous otoacoustic emissions are generated in the _____.

tinnitus (ringing, roaring, or other noises in the ears) has been studied (e.g., Kemp, 1981), but at present, emission behavior cannot explain this symptom in most patients with cochlear impairments.

A signal is now known to emanate from the cochlea between 5 and 20 milliseconds after the presentation of a stimulus introduced into the external ear, and it typically does not exceed 30 dB SPL, regardless of the intensity of the evoking stimulus (Whitehead, Lonsbury-Martin, & Martin, 1992). This signal is called the **transient-evoked otoacoustic emission (TEOAE)**. These so-called “Kemp echoes” are generally described as being in the frequency range between 500 and 4000 Hz. Additionally, when brief pure tones are used as stimuli, the emissions are close to the frequency of the evoking stimulus. To separate the TEOAE from ambient noise in the ear, a number of stimuli are presented and the response waveforms are computer averaged.

The discovery of OAEs is providing a new way of understanding how the auditory system functions, a new means of identifying hearing loss, and another method for determining site of auditory lesion. Some of the clinical applications of OAEs are discussed in Chapters 7 and 13.

Frequency Analysis in the Cochlea

The frequency response of the nerve cells of the cochlea is laid out in an orderly fashion, with the lowest frequencies to which the ear responds (about 20 Hz) at the apical end. The spacing between the nerve fibers is not equal all along the basilar membrane. Fibers for the frequencies between 2000 and 20,000 Hz (the highest frequency to which the ear responds to air-conducted sounds) lie from the midpoint of the basilar membrane to the basal end of the cochlea near the oval window. Fibers for frequencies below 2000 Hz are contained on the other half of the basilar membrane.

Humans are capable of excellent frequency discrimination, in part because auditory nerve fibers are sharply tuned to specific frequencies. The frequency that can increase the firing rate of a neuron above its spontaneous firing rate is called its characteristic frequency or best frequency. Békésy (1960), who was among the first to study the tuning mechanism of the cochlea, observed that the tuning becomes sharper (narrower bandwidth) as frequency is increased (traveling wave peak closer to the basal end of the cochlea), although it is less sharply tuned than the auditory nerve. The slope of the tuning curve is much steeper above the stimulating frequency than below it.

The concept of the **psychophysical tuning curve (PTC)** (e.g., Pick, 1980) has been used to attempt measurements of the cochlea’s frequency-resolving abilities. It seems apparent that when the cochlea becomes damaged its frequency-resolving power may become poorer, but this is not evident in all cases. Preservation of the normal psychophysical tuning curve contributes to the ear’s ability to resolve complex auditory signals, such as speech. Conversely, widening the PTC in damaged ears may help to explain the kinds of speech-recognition difficulties characteristic of patients with cochlear impairment.

Development of the Inner Ear

Differentiation of the inner ear begins during the 3rd week of gestation, and it reaches adult size and configuration by the sixth month. Placodes form early in embryonic life as thickened epidermal plates. The **auditory placode** infolds to form a pit, which closes off to form a capsule. This capsule divides to form a saccular division, from which the cochlea arises, and a utricular division, which forms the semicircular canals and probably the endolymphatic duct and sac. The vestibular portions of the inner ear develop earlier than the auditory portions.

The inner ear springs primarily from entoderm, although the membranous labyrinth is ectodermal in origin. The structure forms initially as cartilage and then changes to bone, usually

by the 23rd gestational week. The cochlea and vestibule reach full size in their primitive form by the 20th week.

The cochlear turns begin to develop at about the 6th week and are complete by the 9th or 10th week. This is a particularly active time of embryogenesis of the inner ear because the endolymphatic sac and duct and the semicircular canals are also forming, and the utricle and saccule are clearly separated. The utricle, saccule, and endolymphatic duct form from the **otocyst**, the auditory vesicle, or sac, that begins its formation at the end of the first month of gestational age.

By the middle of the 8th week the scalae are forming, and the semicircular canals reach adult configuration, including the ampullae with the cristae forming inside. The maculae are also forming within the utricle and saccule, as are the ducts that connect the saccule with the utricle and cochlear duct.

Between the 10th and 12th weeks the organ of Corti has begun to form. By the 18th week adult configuration of the membranous labyrinth has been reached, and by 25 weeks the inner ear has fully formed.

Clinical Commentary

The fact that fetal development takes place so rapidly probably accounts for the observation that interruption of normal development, as by a maternal disease in early pregnancy, can have such dire consequences for the inner ear. **Sensory/neural hearing loss** is the expected result of abnormality of the cochlea. In such cases, air- and bone-conduction sensitivity should be equally depressed in direct relationship to the severity of the disorder. The reasons that air-conduction and bone-conduction results may not be identical in cases of pure sensory or neural hearing loss were discussed in Chapter 4, and some variations should be expected, even though the inner ear theoretically contributes the pure distortional mode of bone conduction.

Hearing Loss and Disorders of the Inner Ear

Disorders of hearing produced by abnormality or disease of the cochlea probably constitute the largest group of hearing losses called sensory/neural, and these would clearly be sensory in nature. Much of cochlear hearing loss originates with pathology at the level of the hair cells. Promising research, based upon early studies on the inner ears of birds and continuing with studies on mammalian ears, is ongoing for possible treatment of damaged hair cells or the regeneration of lost hair cells (Pirvola et al., 2000; Ryals, 2000).

From a lay perspective, persons often think of hearing loss solely in terms of various levels of impairment. In reality, loss of hearing sensitivity can be quite complex, with areas of normal-hearing sensitivity and areas of profound loss coexisting in a single ear. One fact generally agreed on is that as damage or abnormality occurs in the cochlea, loss of hearing sensitivity is not the only symptom. Indeed, a common complaint of patients with sensory or neural hearing loss is not so much that they cannot hear, but that they have difficulty understanding speech. This speech-recognition problem has been called **dysacusis**, to differentiate it from **hypacusis**, which suggests merely a loss of sensitivity to sound. Dysacusis probably results from a combination of frequency and harmonic distortion in the cochlea. As a general rule, patients with greater

10. Cochlear hearing loss most frequently results from pathology involving the _____.

cochlear hearing losses have more dysacusis. Many patients with unilateral hearing losses indicate that a pure tone of a given frequency has a different pitch in each ear, a phenomenon known as **diplacusis binauralis**. At times, patients perceive that a pure tone lacks the musical quality we associate with it and that it sounds like a musical chord or a noise instead. This has been described as sounding like “bacon frying.” Such a lack of perception of tonal quality for a pure tone is called **diplacusis monauralis**.

Causes of Inner-Ear Disorders

Alterations in the structure and function of the cochlea produce more hearing losses than do abnormalities in other areas of the sensory/neural system. Hearing losses may result from either **endogenous** or **exogenous** causes and are significantly more frequent among men than among women (Ciletti & Flamme, 2009). For purely arbitrary reasons, this chapter examines cochlear hearing losses as they relate generally to the patient’s age at onset.

Prenatal Causes

Prenatal causes are those that have an adverse effect on the normal development of the cochlea. It is difficult to know, in cases of congenital hearing loss, the extent of genetic versus environmental factors, or their possible interrelationships in a given patient. For some time it has been known that some forms of hearing loss tend to run in families. Some patients are born with the hearing loss, and others inherit the tendency for abnormalities to occur after birth. This latter form has been called **hereditodegenerative hearing loss**.

All hereditary information is incorporated in a molecule called **DNA** (deoxyribonucleic acid) and is contained in **genes**, which are the blueprints for the hereditary code. The physical manifestation of a trait is called a **phenotype**, and the actual genetic makeup that results in that trait is called a **genotype**. All of the approximately 30,000 genes are strung in a beadlike fashion along **chromosomes**, of which there are 23 pairs: 22 pairs of **autosomes** (nonsex chromosomes) and one pair of sex chromosomes. One chromosome from each pair is inherited from each parent and is randomly selected. Different forms of a gene are called **alleles**. If an allele is inherited from both parents, that trait is said to be **homozygous** (pure); if the alleles are different, this is called **heterozygous** (mixed).

Hereditary disorders can take a variety of forms. When a gene from only one parent is required for a trait to be shown, that allele is said to be dominant. If the allele from both parents is required for a trait to be shown, it is called recessive. **Autosomal dominant** hearing losses are relatively obvious, since each child has a 50% chance of inheriting the disorder, and a family pattern can be observed. In some cases, the dominant gene is not penetrant; that is, it does not show up phenotypically, and the hearing loss appears to skip one or more generations. Further complicating this matter is the factor of **variable expressivity**, which means that not all the signs of a hereditary condition may appear phenotypically.

Autosomal recessive inheritance accounts for about 80% of profound genetic hearing impairments, about half of which are associated with syndromes. Children with autosomal recessive hearing loss usually have two parents with normal hearing who are **carriers** of the recessive gene, resulting in a 25% chance of that gene being passed on with each pregnancy to the child, who would manifest the hearing loss, and each normal-hearing child having a two in three chance of being a carrier.

11. Hereditary conditions requiring a gene from both parents to manifest a trait are called _____.

12. Prenatal disorders are those that occur _____.

Although both of a female's sex chromosomes (labeled X) carry considerable genetic information, called **X-linked**, the male sex chromosome (which is smaller and labeled Y) contains only the information required to produce the male sex. Many recessive alleles for hearing loss are X-linked, so that a female child receiving an allele for hearing loss from one parent will not show the trait; but a male child, not having the corresponding normal gene, will probably develop the hearing loss. A female who is heterozygous for an X-linked recessive hearing loss will not have a genetic hearing loss but will be a carrier and produce sons, each of whom will have a 50% chance of having the hearing loss, and daughters, each of whom will have a 50% chance of being a carrier. Males with X-linked hearing loss have sons who do not show the trait and daughters who would be carriers. Multifactorial hereditary disorders are the result of **multifactorial genetic considerations**, combinations of hereditary and environmental factors.

Cases of hereditary hearing loss have been documented in patients with no associated abnormalities, as well as in association with external ear, skull, and facial deformities; cleft palate; optic disorders; changes in eye, hair, and skin pigmentation; thyroid disease; disorders of the heart; musculoskeletal anomalies; mental retardation; difficulty with balance and coordination; and other sensory and motor deficits. Whenever a group of symptoms is considered together for the diagnosis of a particular disorder, such a combination of signs is called a **syndrome**.

Websites that provide instruction on a variety of syndromes related to hearing loss are provided at the end of this chapter.

At times, portions of the chromosomes are missing, or extra material is found. In some cases an extra (third) chromosome is present; this is called **trisomy**. In cases of chromosomal disorders, the parents may be perfectly normal, but the fetus may have difficulty in surviving the pregnancy or may be severely impaired. For reasons not entirely understood, women above the age of 40 show an increased risk of bearing children with trisomic chromosomal disorders, such as Down syndrome.

The argument over the influences of heredity versus environment has gone on for a very long time and is probably counterproductive. Those who favor the former adopt a philosophy of "biological determinism" and tend to ignore the myriad of environmental factors that influence all aspects of the human condition, not the least of which are the functions of the inner ear and the brain. The wide variety among humans cannot be explained on the basis of genes alone. As a matter of fact, the Human Genome Project revealed that of the 30,000 human genes there is only a difference of one gene between humans and chimpanzees and only several hundred differences between humans and mice.

It is unknown how many disorders are determined primarily by heredity, but it is likely that genetics plays a major role in many conditions. As researchers perfect the science of gene mapping, the potential for altering the course of future diseases of all kinds brings an understandable excitement. Nevertheless, some medical ethicists fear that knowledge of an individual's susceptibility to a variety of conditions may carry with it a number of sociological dilemmas.

Different audiometric configurations have been suggested as *typical* of a given cause. There is, however, no unanimity on hereditary hearing loss, and clearly some cases may be moderate-to-severe bilateral losses with flat audiograms (Figure 11.8) or predominantly high-frequency or low-frequency patterns. Some losses have been described as typically unilateral.

13. True/False
Hereditary hearing loss is identifiable through its characteristic sloping high frequency hearing loss.

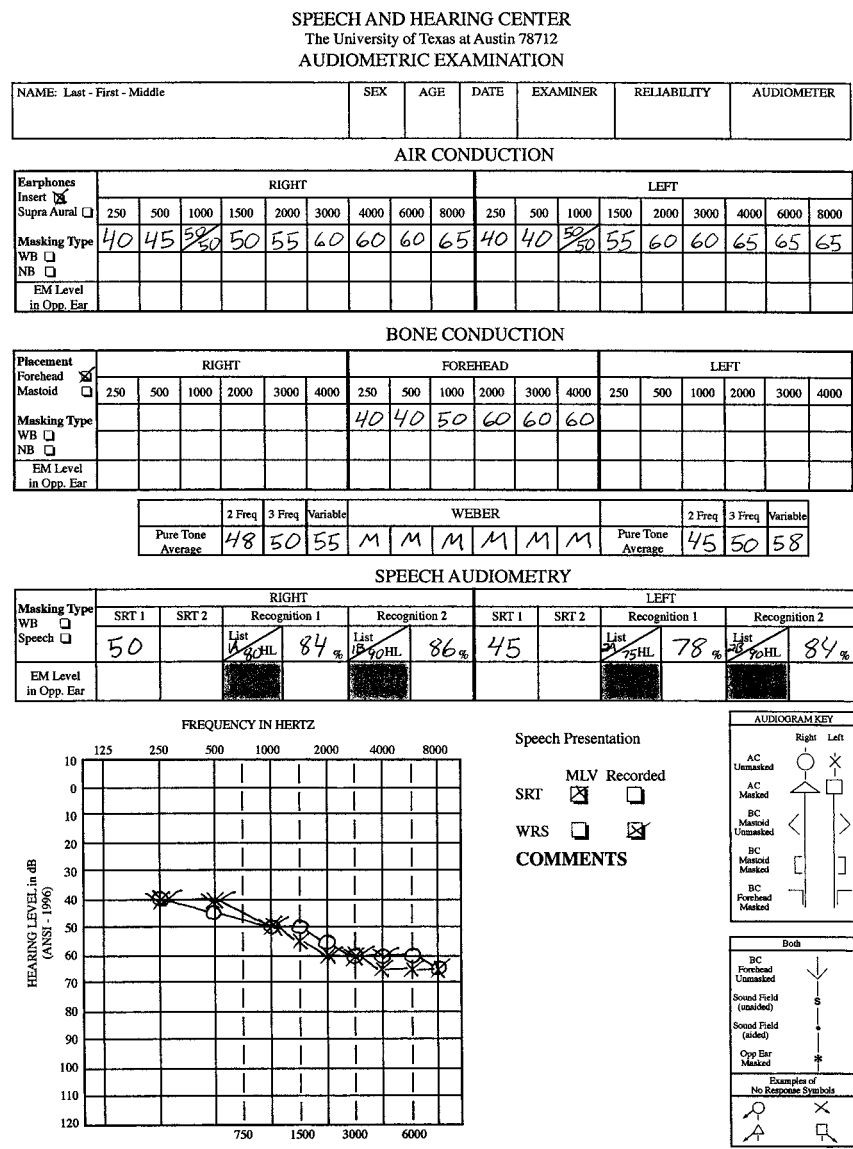


FIGURE 11.8 Audiogram showing a moderate sensory/neural hearing loss in both ears. The contour of the audiogram is relatively flat and reveals approximately equal hearing loss at all frequencies. The SRTs and the two-frequency and three-frequency pure-tone averages are in close agreement, and the word-recognition scores show some difficulty in understanding speech.

Problems associated with the Rh baby have become fewer in recent years as physicians have learned to predict and prevent the disorders with maternal immunization and infant blood transfusion immediately after birth. The danger presents itself when a fetus whose blood contains the protein molecule called the **Rh** (rhesus) **factor** is conceived by a mother in whom the factor is absent. The mother's body produces antibodies for protection against the harmful effects of the Rh factor, and this antibody count is increased with succeeding pregnancies. Usually by the third pregnancy there is a sufficient number of antibodies so that the developing red blood cells of the fetus are damaged to the extent that they cannot properly carry oxygen to

essential body parts, including the cochlea. In addition, the blood of the newborn child may carry bilirubin (a component of liver bile) in increased concentration, so that it may become deposited in the cochlea and produce a sensory hearing loss.

In addition to hearing loss, Rh incompatibility can result in a number of abnormalities in the newborn, including **cerebral palsy**. Cerebral palsy may be defined as damage to the brain, usually congenital, that affects the motor and frequently the sensory systems of the body. There are numbers of causes of cerebral palsy, many of which are associated with sensory hearing loss. Athetotic cerebral palsy, or **athetosis**, wherein the patient exhibits an uncontrolled writhing or squirming motion, has long been associated with hearing loss. Years ago it was assumed that because cerebral palsy is the result of brain damage, the hearing loss is also produced by damage in the central auditory nervous system. There is evidence that in many cases the damage is cochlear. Because the hearing loss that accompanies athetotic cerebral palsy is often in the high frequencies, it may escape detection for years, masked by the more dramatic motor symptoms and often mental retardation.

In the 1960s, thalidomide, a tranquilizing drug first used in Europe, was introduced to pregnant women. The drug was allegedly free from unwanted complications, but this lack of side effects was more apparent than real, as evidenced by the number of children born with horrible birth deformities to mothers who had taken the drug. The most dramatic symptom was missing or malformed arms and legs; in addition, although it was not generally known, disorders of hearing also afflicted a large number of the thalidomide babies. Because large quantities of drugs, both legal and illegal, are being consumed by women of child-bearing age, it is probable that future research will disclose that many of these also contribute to congenital hearing loss.

Although a pregnant woman must always be fearful of contracting a viral disease, the fear is greatest during the first trimester (three months) of pregnancy, when the cells of the inner ear and central nervous system are differentiating most rapidly. For many years probably the most dreaded viral infection was rubella, or German measles, as it is one of the few viruses that cross the placental barrier. Although this disease was known to be mild, or even asymptomatic in the patient, the effects on the fetus may be devastating.

The latest major rubella epidemic was seen in 1964 and 1965, with a reported 12.5 million cases and 20,000 infants born with congenital rubella syndrome (CRS). The introduction of a vaccine in 1969 reduced the number of reported cases drastically; however, there have been several resurgences through the years, mostly among the poor and religious groups that forbid vaccination. Statistics in developing countries are not readily available, so CRS continues to be a health threat.

Rubella babies tend to be smaller at birth and to develop more slowly than normal infants. They are shorter, weigh less, and have head circumferences that are less than normal. Common results of maternal rubella are brain damage, blindness, heart defects, mental retardation, and sensory hearing loss. The rubella hearing-impaired child presents special difficulties in habilitation and education because of the probability of multiple disorders.

Viral infections may actually kill or destroy cells, or they may slow down the rate at which each cell can divide and reproduce by mitosis. The rubella baby has normal-size cells, but fewer of them. It is not always clear whether the virus has affected the fetus by crossing the placental barrier or by contagion during the birth process. As the maternal body temperature increases in response to a viral or other infection, the oxygen requirement of the fetus increases dramatically. Oxygen deprivation is called **anoxia** and may result in damage to important cells of the cochlea.

Of all the congenital abnormalities produced by maternal rubella in the first trimester of pregnancy, hearing loss is the most common (Karmody, 1969). The main development of the cochlea occurs during the 6th fetal week and of the organ of Corti at the 12th week, making these critically susceptible times.

It is highly likely that the virus enters the inner ear through the stria vascularis, which would explain why the cochlea, rather than the vestibular apparatus, is usually affected. Alford (1968) has suggested that the rubella virus remains in the tissues of the cochlea even after birth. If destruction of cochlear tissue continues, the child may experience a form of progressive hearing loss that might not be associated with a prenatal cause and may elude early identification through newborn screening.

14. True/False

Some forms of neonatal hearing loss may have a delayed onset eluding early identification through newborn hearing screening programs.

For about three decades there has been a major focus on the **acquired immune deficiency syndrome (AIDS)** and on the **human immunodeficiency virus (HIV)** found in those with AIDS. Mothers with HIV have a 50% chance of delivering a baby with the disease (Lawrence, 1987). How HIV affects the cochlea and the incidence with which this occurs are not known, although long-term treatment with corticosteroids has resulted in the reversal of some hearing losses and the arrest of the progression of others. Viral infections in the unborn are far more likely to occur when the mother suffers from a disease-causing deficiency in her immune system.

Probably a major cause of prenatal sensory hearing loss is **cytomegalovirus (CMV)**, a seemingly harmless, and often-asymptomatic illness that is a member of the herpes group of viruses. The cause of the problem is an infection called cytomegalic inclusion disease (CID). When the developing fetus is infected, a variety of physical symptoms may be present, in addition to hearing loss. About 31% of infants infected with CMV have a serious hearing loss (Johnson, Hosford-Dunn, Paryani, Yeager, & Malachowski, 1986).

Cytomegalovirus may be transmitted from mother to child in several ways:

1. Prenatally: It may be transmitted through the placenta.
2. Perinatally: The infant may contract the virus from the cervix of an infected mother during the birth process.
3. Postnatally: The virus may be transmitted in the infected mother's milk.

Since CMV is potentially so devastating, it is curious to note that there is little active pursuit of neonatal screening for this disease. This would require only a simple test, since the virus is present in the urine of all infected newborns. As a harbinger of potential acquired hearing loss, early detection of CMV can be beneficial from any point of view.

When CMV is acquired perinatally or postnatally, there are usually no serious side effects in the child. Unlike rubella, CMV does not warn an expectant mother with a telltale rash or other symptoms. Another difference is that at present there is no vaccine to prevent CMV.

Perinatal Causes

Perinatal causes of hearing loss are those that occur during the process of birth itself. Such causes frequently produce multiple handicaps.

A common cause of damage both to the cochlea and to the central nervous system is anoxia, deprivation of oxygen to important cells, which alters their metabolism and results in damage or destruction. In the newborn, anoxia may result from prolapse of the umbilical cord, which cuts off the blood supply to the head; from premature separation of the placenta; or from a wide variety of other factors.

Accumulations of toxic substances in the mother's bloodstream may reduce the passage of oxygen across the placenta, which also results in anoxia. The fetus may also suffer from damage

produced by the toxic substances themselves. For this reason, pregnant women should cautiously avoid exposure to contagious diseases such as hepatitis.

Prematurity is determined by the weight of the child at the time of birth, and not necessarily by the length of the pregnancy, as the word itself suggests. When infants weigh less than 1500 grams (3.5 pounds) at birth, they are considered premature. Prematurity is often associated with multiple births, and both are associated with sensory hearing loss.

It is common practice to place premature infants in incubators so that, at least for the early days of life, their environments can be carefully controlled. Care must be taken not to over-administer oxygen, because this produces retinal defects. At one time some motors operating incubators were found to produce extremely high noise levels (up to 95 dB SPL). Hearing losses in children thus treated may have been produced by noise, rather than, or in addition to, the results and causes of prematurity.

Trauma to the fetal head, either by violent uterine contractions or by the use of “high forceps” during delivery, may also result in damage to the brain and to the cochlea. It is possible that the head trauma itself does not produce the damage; instead, the initial cause of the difficulty in delivery may be the cause of the hearing loss.

15. A child is judged premature when birth weight is under _____.

Postnatal Causes

Postnatal causes of cochlear hearing loss are any factors occurring after birth. An often-named cause is otitis media. The toxins from the bacteria in the middle ear may enter the inner ear by way of the round or oval window, or pus may enter the labyrinth from the middle ear or from the meninges, the protective covers of the brain and spinal cord. Bacterial **meningitis**, inflammation of the meninges, may cause total deafness, because if the labyrinth fills with pus, as healing takes place, the membranes and other loosely attached structures of the labyrinth are replaced by bone. Early treatment with corticosteroids may arrest the hearing loss before it becomes severe. If the enzymes produced by the infectious process enter the cochlea by diffusion through the round window, a hearing loss will surely result. Often, patients with primarily conductive hearing losses produced by otitis media begin to show additional cochlear degeneration, resulting in **mixed hearing loss** (Figure 11.9).

Some viral infections have definitely been identified as the causative factors in cochlear hearing loss. These infections include measles, mumps, chickenpox, influenza, and viral pneumonia, among others. The two most common are measles (rubeola) and mumps (parotitis). Rubeola, the 10-day variety of measles, carries a significantly greater threat to the patient than does rubella. Rubeola can involve much more than the rash with which it is associated and can take a terrible toll on the patient. In addition to hearing loss, rubeola can cause heart defects, disorders of the central nervous system, and even death in severe cases. Rubeola may cause a sudden hearing loss that may not begin until some time after the other symptoms disappear. Mumps is an inflammation of the parotid (salivary) gland located on either side of the neck near the ear. When the salivary duct becomes blocked because of the viral infection, the result is the familiar lump in the neck, but neither the side of the neck most swollen, nor the degree of swelling has an effect on the degree of hearing loss that results. Both measles and mumps may be increasing in occurrence, in part due to complacency involving vaccination of small children.

Most virus-produced hearing losses are bilateral, but some viral infections, notably mumps, are associated with unilateral losses as well. Everberg (1957) estimates an incidence of

16. Perinatal disorders are those that occur _____, whereas postnatal disorders are those that occur any time _____.

SPEECH AND HEARING CENTER
The University of Texas at Austin 78712
AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐	RIGHT								LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000
Masking Type WB ☐ NB ☐	60	65	70	70	75	80	80	85	85	55	55	60	60	60	70	75	75	70
EM Level in Opp. Ear																		

BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT						FOREHEAD						LEFT					
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type WB ☐ NB ☒	15*	25*	35*	50*	55*	55*	15	25	35	50	55	55	20*	35*	45*	50*	55*	55*
EM Level in Opp. Ear	55	55	60	60	70	75							70	80	85	75	80	80

	2 Freq	3 Freq	Variable	WEBER				2 Freq	3 Freq	Variable
Pure Tone Average	68	70	75					58	58	65

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☒	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
	70		List 1 90 HL	80* HL	60		List 1 90 HL	76* HL
EM Level in Opp. Ear			50				60	

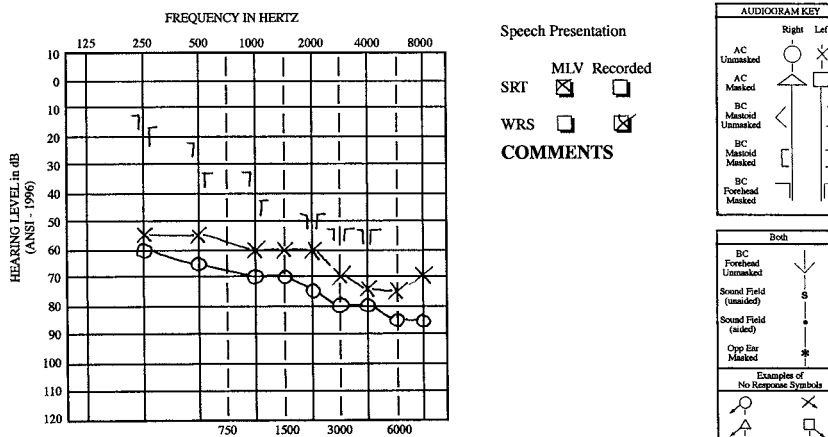


FIGURE 11.9 Audiogram showing a mixed hearing loss in both ears. Repeating bone conduction with masking was indicated because of the air-bone gaps. The impaired word-recognition scores reflect the sensory/neural component of the loss.

hearing loss from mumps at 0.05 per 1,000 in the general population. Although the precise mechanism producing hearing loss from mumps is not clear, it seems likely that the route of infection is the bloodstream. Other theories, such as general infection of the labyrinth, would not explain why vestibular symptoms are frequently absent.

A disease once thought to be on the decrease, but now recognized as quite the opposite, is syphilis. This disease may be prenatal or acquired, and it often goes through three distinct but overlapping stages. Because its symptoms may resemble those of a number of different systemic diseases, it has been called the "great imitator." Brain damage is a frequent

sequela of syphilis, but the cochlea may also be involved. A number of bizarre audiometric patterns have been associated with syphilis, and the variations are so great that a typical pattern does not emerge.

Infections of the labyrinth are called **labyrinthitis** and may affect both the auditory and vestibular mechanisms, producing symptoms of hearing loss and vertigo. The causes of labyrinthitis are not always known, and the condition is frequently confused with other causes of hearing loss; however, tuberculosis, syphilis, cholesteatoma, or viral infection may be implicated.

The body's natural response to infection is elevation of temperature. When the fevers become excessive, however, cells, including those of the cochlea, may become damaged. Sometimes children run high fevers with no apparent cause, but with ensuing hearing loss. When such histories are clear-cut, it is tempting to blame the fever, even when it would be logical to suspect the initial cause of the fever, such as a viral infection, as the real cause. In many cases, diagnosis of the primary cause of a hearing loss is mere speculation.

Infections of the kidneys may result in the deposit of toxic substances in the inner ear. Kidney disease may prevent medications from being excreted, thereby raising their levels in the blood abnormally high and producing ototoxicity. Other illnesses, including diabetes, have also been directly linked to cochlear damage.

Toxic Causes of Cochlear Hearing Loss

It has been said that progress has its side effects. This is notably true of the side effects of antibiotics, the wonder drugs that have saved many lives in the last six decades. Most noted among the drugs that are cochleotoxic (i.e., cause hearing loss) are dihydrostreptomycin, viomycin, neomycin, and kanamycin. Because hearing losses ranging from mild to profound may result from the use of these drugs, it is hoped that they are not prescribed unless it is fairly certain that other drugs, with fewer or less severe side effects, will not be just as efficacious. Vestibulotoxic drugs (those that are known to affect the vestibular organs) include streptomycin and gentamycin.

Tuberculosis, which only a short time ago was declining in frequency, is experiencing resurgence. This disease can cause cochlear hearing loss, especially when the prolonged use of **ototoxic** drugs is mandatory, such as in tuberculosis sanatoria, and the patient's hearing should be monitored frequently so that any loss of hearing, or its progression, may be noted. In such cases, decisions regarding continued use of the medication must be made on the basis of the specific needs of the patient. Although the final decision on drug use is always made by a physician, it is within the purview of audiologists to make their concerns over hearing loss known.

Quinine is a drug that has long been used to combat malaria and to fight fever and reduce the pain of the common cold. Many patients who have taken this drug have complained of annoying tinnitus and hearing loss. Although with less frequency, quinine is still prescribed for certain disorders and continues to be marketed as an over-the-counter medication.

Other drugs that have been associated with hearing loss include aspirin, certain diuretics, nicotine, and alcohol. It is usually expected that these drugs will not affect hearing unless they are taken in large amounts and over prolonged periods of time. Certainly, there are many individuals who appear to consume these substances in what might be considered excess with no side effects. The individual's own constitutional predispositions must surely be a factor here.

For some time it has been recognized that hearing loss from ototoxic drugs initially occurs, in most cases, in the high-frequency range (Jacobson, Downs, & Fletcher, 1969). Thus, physicians prescribing potentially ototoxic drugs often have time to consider alternate medications before the hearing loss encroaches on the frequencies that are more essential to discriminating speech. One of the difficulties in testing ultra-audiometric frequencies (above 8000 Hz) has been the

17. Drugs taken by the patient that produce hearing loss are called _____ and typically affect _____ frequency hearing.

interference patterns that are set up when pure tones with short wavelengths are presented to the external auditory canal. Even slight differences in placement of the earphone may cause difficulty. That problem has been lessened with the use of insert earphones (Valente, Valente, & Goebel, 1992). Using extended high-frequency audiometry can assist in detecting early hearing loss from noise, chemotherapy, kidney disease, and otitis media, as well as ototoxicity, and can be helpful in understanding some causes of tinnitus in patients who have normal hearing through the usual audiometric frequency range.

ASHA (1994) has published guidelines for monitoring patients who receive cochleotoxic drugs. Elements of these guidelines include the following:

1. Specific criteria for identification of toxicity.
2. Timely identification of at-risk patients.
3. Pretreatment counseling regarding potential cochleotoxic effects.
4. Valid baseline measures (hearing tests) performed before treatment or shortly after treatment begins.
5. Periodic monitoring evaluations at intervals timed to document progression of hearing loss.
6. Follow-up evaluations to determine post-treatment effects.

In addition to prescribed medications that can be ototoxic, some so-called recreational drugs can create irreversible hearing loss. Bilateral sensory/neural hearing loss arising from both cochlear and neural pathology can result from cocaine or heroine use in isolation and in combination as in “speedballing” (Fowler & King, 2008).

Otosclerosis

As mentioned in Chapter 10, otosclerosis is a disease of the bony labyrinth that causes a conductive hearing loss when the new bone growth affects either the oval window or the round window. Although it is uncommon, if otosclerosis involves the cochlea, sensory or mixed hearing loss results, which may be either bilateral or unilateral. Although there are no binding rules, the audiometric configuration is generally flat, and speech recognition is not severely affected. There is a characteristic appearance of this condition that can be seen on CT scans but not MRIs. Attempts have been made to arrest the progression of cochlear otosclerosis with sodium fluoride, but the effectiveness of this treatment has not been proved.

Barotrauma

Barotrauma was mentioned as a cause of conductive hearing loss. In addition, sudden changes in middle-ear pressure, as from diving, flying, or even violent sneezing, may cause a rupture of the round window or a tearing of the annulus of the oval window. The resulting fistula (perilymph leak) can often be surgically repaired and may reverse a permanent or fluctuating cochlear hearing loss and/or vertigo. Barotrauma can produce a mild-to-profound hearing loss.

Noise-Induced Hearing Loss

The industrial revolution’s introduction of high levels of noise brought a greater threat to the human auditory system than evolution had prepared for. Documented cases of noise-induced hearing loss go back more than 200 years. Hearing losses from intense noise may be the result of

brief exposure to high-level sounds, with subsequent partial or complete hearing recovery, or of repeated exposure to high-level sounds, with permanent impairment. Cases in which hearing thresholds improve after an initial impairment following noise are said to be the result of **temporary threshold shift (TTS)**; irreversible losses are called **permanent threshold shift (PTS)**.

A number of agents may interact with noise to increase the danger to hearing sensitivity. Research has shown that aspirin, which has been known to produce reversible hearing loss after ingestion, synergizes with noise to produce a greater temporary threshold shift than would otherwise be observed (McFadden & Plattsmier, 1983). Although the effects of aspirin on permanent hearing loss have not been demonstrated, it certainly seems prudent for audiologists to advise that people who must be exposed to high levels of noise should refrain from taking this drug, at least at times closely related to exposure.

Men appear to have a higher incidence of hearing loss from noise than do women (Ewertson, 1973), perhaps because as a group they have greater noise exposure, both on the job and during leisure activities. This tendency may indeed have an earlier origin, as the prevalence of noise-induced threshold shift among U.S. children age 6 to 19 years is greater than 14% among boys, while the prevalence stands at a lower 10% among girls (Niskar et al., 2001). There is evidence that children are suffering increased amounts of hearing loss from such items as toy phones, musical instruments, fire-crackers, stereo systems, and toy guns, some of which produce noise levels up to 155 dBA (Nadler, 1997). The fact that children's arms are shorter than adults' results in anything noisy held in the hand being closer to the ear. Although there are recommended guidelines for childhood hearing screening (see Chapter 7), there are no U.S. federal mandates for screening within this population. Clearly, hearing awareness should be presented to school-age children as part of any activities that may be considered by the school speech-language pathologist or educational audiologist for May Better Hearing and Speech Month or October Audiology Awareness Month.

Postmortem electron microscope studies have shown loss of hair cells and their supporting structures in the basal end of the cochlea and nerve degeneration in the osseous lamina (Johnson & Hawkins, 1976) in patients with noise-induced hearing loss. The hearing loss may be due to biological changes in the sensory cells, physical dislodging of hair cells during high sound-level stimulation, changes in the cochlear blood supply with consequent alterations in the function of the stria vascularis, loss of the outer hair cells, rupture of Reissner's membrane, detachment of the organ of Corti from the basilar membrane, or a variety of other causes.

An electron-microscopic view of hair-cell damage secondary to acoustic trauma may be viewed under "Ear Pathology" in the Learning Supplements section of the Companion Website.



Acoustic trauma is the term often used to describe noise-induced hearing loss from impulsive sounds such as explosions and gunfire. A typical audiometric configuration has emerged, shown in Figure 11.10, depicting what has been called the **acoustic trauma notch**. Characteristically, the hearing is poorest in the range between 3000 and 6000 Hz, with recovery at 8000 Hz, suggesting damage to the portion of the basal turn of the cochlea related to that frequency range. As a rule, the amounts of hearing loss are similar in both ears when individuals acquire noise-induced hearing losses in the workplace. Rifle shooters generally show more hearing loss in the ear opposite the shoulder to which the rifle stock is held; that is, right-handed shooters will have more hearing loss in their left ears. A survey in Canada on noise-induced hearing loss in truck drivers revealed greater loss in the left ear, probably produced by the rush of air past the open window on the driver's side (Dufresne, Alleyne, & Reesal, 1988).

SPEECH AND HEARING CENTER
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AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐	RIGHT								LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000
Masking Type WB ☐ NB ☐	5	0	5	5	10	25	60	35	20	0	0	5	10	20	40	70	55	25
EM Level in Opp. Ear																		

BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT						FOREHEAD						LEFT					
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000
Masking Type WB ☐ NB ☐							0	5	5	15	35	65						
EM Level in Opp. Ear																		

	2 Freq	3 Freq	Variable	WEBER				2 Freq	3 Freq	Variable
Pure Tone Average	3	5	25					3	8	32

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☒	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
	5		List 12 55 HL 96 %	List 12 40 HL 94 %	5		List 12 35 HL 94 %	List 12 25 HL 94 %
EM Level in Opp. Ear				25				20

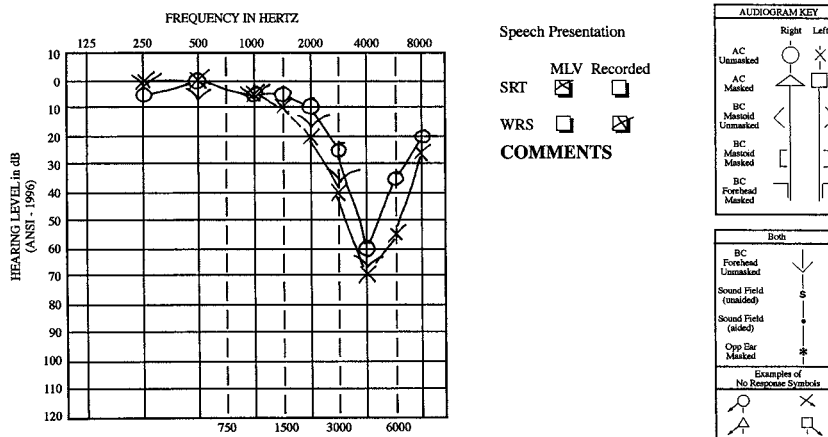


FIGURE 11.10 Audiogram showing a typical acoustic trauma notch at 4000 Hz. SRTs and WRSs are normal, showing little difficulty in quiet because the hearing loss is primarily above the critical frequency range for hearing and understanding speech. It can be expected that the patient experiences considerable difficulty in understanding speech in the presence of background noise, and additional speech audiometrics to objectively demonstrate this should be considered. Note that the two- and three-frequency pure-tone averages fail to reflect any loss of hearing sensitivity.

The acoustic trauma notch is not found in all cases of noise-induced hearing loss, nor is it restricted to this cause. It is, however, strongly suggestive of noise and should be corroborated with supporting evidence, such as the clinical history. If noise-induced hearing loss is suspected, hearing should always be tested at 3000 and 6000 Hz, even if sensitivity at adjacent octave and midoctave frequencies is normal.

Industrial noise is a factor long recognized as a cause of hearing loss. The term “boiler-maker’s disease” was coined many years ago to describe the hearing losses sustained by men working in the noisy environs of that industry. Although boilermakers may be fewer in number today, modern technology has produced new and even noisier industries. Exposure to jet engines, drop forges, pneumatic hammers, subways, loud music, and even computers, has been documented as causing hearing loss. Fifty years ago, a study of the effects of noise on hearing revealed that older populations in societies that have lower noise-exposure levels exhibit better hearing sensitivity than do those populations in other societies (Rosen, Bergman, Plester, El-Mofly, & Hammed, 1962). Of course, differences in diet, lifestyle, and so on may also account for the better hearing sensitivity of the older members of more primitive societies.

18. Noise-induced hearing loss is generally caused by damage to the _____ and frequently results in a notch in the _____ Hz range on the audiogram.

Noise in society is an ever-increasing problem. Millions of dollars are paid to military veterans in compensation for hearing loss, which is the largest compensable disability among veterans: a disability likely to increase given the increase in global hostilities. Insurance companies, whose coverage includes noisy industries, have been forced to become increasingly concerned with the effects of noise on hearing. Aside from the psychological, social, and vocational handicaps imposed on patients with noise-induced hearing loss, the financial figures have led to concern on the part of government and industry alike.

After a number of proposals, lawsuits, and reversals, the Occupational Safety and Health Administration (OSHA) (1983) has recommended a scale on which the time that a worker may be safely exposed to intense sounds is decreased as the intensity of the noise is increased. Under this rule, the maximum exposure level before hearing conservation measures must be implemented is 85 dBA for an eight-hour work day. For every 5 dB increase in noise above 90 dBA, the allowable exposure time is cut in half. While OSHA’s standards for hearing conservation have the legal backing of a federal regulation, the National Institute of Occupational Safety and Health (NIOSH) has promulgated guidelines that for many audiologists are becoming the benchmark for standard of care (NIOSH, 1998). The NIOSH guidelines are more stringent than those set by OSHA in several areas including noise monitoring, noise exposure limits, hearing monitoring practices, and the training of audiometric technicians. For example, NIOSH endorses a more protective 3 dB time-intensity tradeoff rather than OSHA’s 5 dB exchange rate. Table 11.1 contrasts the OSHA recommended noise standard with the more stringent NIOSH recommendations.

Sound-level meters, or individually worn noise dosimeters, are used to measure the intensity of sound in noisy areas, such as in factories and around aircraft, to determine

TABLE 11.1 Maximum Sound Exposure Levels as a Function of Duration of Exposure Set to Protect Workers’ Hearing*
(NIOSH, 1998; OSHA, 2010).*

<i>dB SPL</i>	85	88	90	92	94	95	97	100	105	110	115
NIOSH (Hour Limit)	8	4			1	3/4	1/2	1/4			
OSHA (Hour Limit)	16	8	6		4	3	2	1	1/2	1/4	

Note: Lawnmowers, subways, and truck traffic can measure above 90 dBA.

Rock concerts, band practices, and car stereos with aftermarket subwoofers are frequently measured in excess of 110 dBA.

*Modified from Niquette & Eply, 2010.

whether the noise levels fall within or exceed the **damage-risk criteria** set up by OSHA or recommended by NIOSH. The use of any damage-risk criteria is oversimplified, in part because the specified intensities listed do not take into consideration the concentration of sound energy in different frequency bands. In addition, the impulsive characteristics of offending sounds have also not been considered because most of the sound-level meters used have an averaging time of about 125 milliseconds, while the peaks of many sounds occur within 25 to 50 microseconds. Because it takes some time for the brain to average the sounds, they may be more intense than their psychological interpretations appear and therefore more dangerous than thought.

19. The device used to measure the intensity of sound in the environment is called a _____.

Lipscomb (1992) points out that readings from noise dosimeters can be misleading and can appear substantially different, depending on how the instrument is set. Hearing conservation is really not an area in which audiologists should merely dabble without the proper background and knowledge.

Because of the increasing interest in noise-induced hearing loss in industry, a number of hearing-conservation programs have been developed in the United States and around the world. Lipscomb (1992) defines a comprehensive hearing conservation program (HCP) as one that (1) identifies people who are at risk for noise-induced hearing loss, (2) abates dangerous noise levels as economically as possible, and (3) protects employees who are at risk for noise-induced hearing loss.

Workers are being advised about the dangers of noise and are encouraged to wear hearing protectors such as those shown in Figures 11.11 and 11.12. It is likely that hearing protectors may provide a false sense of security, assuring wearers that they are “safe” from noise damage.

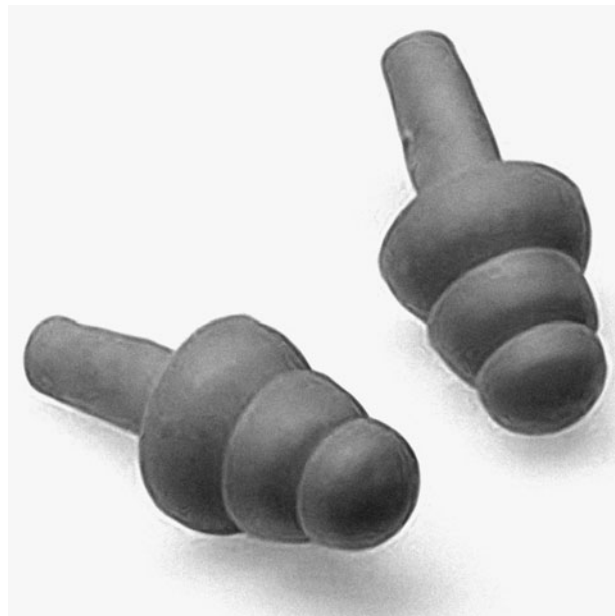


FIGURE 11.11 Commercial earplugs designed to attenuate high noise levels. (Courtesy of Oaktree Products, Inc.)



FIGURE 11.12 Commercial earmuffs designed to be worn in areas of intense noise. (Courtesy of Oaktree Products, Inc.)

However, many problems are associated with fitting and wearing hearing protectors and the amount of sound attenuation found in the laboratory may be considerably more than that actually obtained on the job (Berger & Casali, 2000). The more experience individuals have in fitting earplugs in their own ears, the greater the sound attenuation provided. Davis, Richards, and Martin (2007) reported no significant difference in the attenuation provided by muff-style hearing protection for untrained users and those trained in the use of muffs. However, four other styles of hearing protectors were found to provide either significantly greater attenuation or less variability in the attenuation provided when users were given direct instruction in their use, speaking to the importance of the audiologist's direct involvement in the selection and initial use of hearing protectors. Audiologists should warn hearing-aid users that the hollow shell of a turned-off hearing aid provides little effective protection.

20. True/False

The effectiveness of insert type hearing protectors is significantly increased following specific instruction on proper use.

A demonstration of the proper use of earplugs and earmuffs as hearing protection devices may be seen in the video titled "Hearing Protection" in the Clinical Demonstrations section of the Companion Website.



Many preemployment physical examinations now include pure-tone audiometry, but OSHA (1983) requires the first test to be carried out within six months of employment. After that, annual tests (defined as no further apart than 15 months) must be made. Routine tests may be contaminated by recent noise exposure, and the amount of temporary threshold shift and time

to recovery is determined, in large part, by the intensity of the previous exposure. According to Melnick (1984), some TTS does not recover for a week or even longer.

The amount of hearing loss shown by a person exposed to high noise levels in the workplace can vary for many reasons. Genetic factors are always a consideration, as are disease, aging, and noise exposure off the job site. The insidious nature of noise-induced hearing loss often results in long delays before the onset of hearing problems and consultation with a hearing specialist.

A surprising amount of the noise-induced hearing loss seen today is caused by other than work-related activities. It has been known, almost since their innovation, that airbag deployment can cause hearing loss, tinnitus, hyperacusis, and balance disorders (Price & Kalb, 1999). This is not surprising, given that an airbag impulse can generate a noise from 160 to 170 dB SPL. Many millions of people are engaged in hobbies involving motorboats, snowmobiles, motorbikes, and race cars, in addition to the use of guns. What may be viewed as quieter recreation may even pose potential risk to participants. Documented noise levels when using some styles of thin-faced titanium golf clubs can create an impact noise at ear level approaching 130 dB SPL, which may be sufficient to produce either temporary or permanent hearing threshold shifts for susceptible golfers (Buchanan, Wilkinson, Fitzgerald, & Prinsley, 2008). The term “recreational audiology” has been coined to describe the activities of professionals involved in finding these hearing losses and recommending appropriate precautionary steps.

Exposure to intense sounds by professional musicians has caused a special concern for this group. Musicians generally rely more on the sense of hearing than many others who suffer from noise-induced hearing loss and may spend many hours a day exposed to intense sounds. Aerobic instructors and their students may be at particular risk from intense music exposure, as studies have suggested that physical exercise plus noise results in greater threshold shifts than exposure to noise alone (Vittitow, Windmill, Yates, & Cunningham, 1994), possibly due to the effects on the cochlea of changes in metabolic activity during exercise. It is not just musicians and music lovers who can put themselves at risk of the adverse effects of intense sound. A coincidental finding for beluga whales reveals that music played above 95 dBA SPL for more than two hours in the festivities ballroom of the Georgia Aquarium not only can be harmful to human hearing but is transferred through the viewing window of the adjacent marine mammal aquarium at levels sufficient to generate stress in the captive whales (converted to dB relative to 1 micropascal [μ Pa] for underwater measures) (Scheifele, Clark, Miller, Gaglione, & Starke, 2009).

The original impetus for the birth of the audiology profession was acquired hearing loss following military service in World War II, and modern weaponry continues as a major contributor to noise-induced hearing loss (Figure 11.13). The Department of Veterans Affairs has ranked tinnitus and hearing loss as the two most frequent disabilities in the “war on terror” (U.S. Department of Veterans Affairs, 2008). Nearly 100,000 troops who have served in Iraq and Afghanistan collect disability for tinnitus with the numbers on disability for permanent hearing loss not far behind.

A patient with apparent noise-induced hearing loss should be advised to limit further exposure to loud noise and to use protective earplugs or muffs whenever exposure is necessary. Periodic hearing examinations to monitor progression should also be encouraged. Hunters, target shooters, and snowmobile drivers are often a particularly difficult group to work with because of their reluctance both to wear hearing protectors and to limit their sport. Music enthusiasts who use stereo headphones or portable stereo systems are often at risk for hearing loss because of the high levels of sound delivered directly to their ears. Special hearing protection that does not distort sound quality is available for musicians. Some audiologists have found a new market in the area of recreational audiology as they work toward addressing the hearing protection needs of those whose hobbies endanger their hearing.



FIGURE 11.13 Military personnel are regularly exposed to damaging noise levels. Unexpected roadside bombs, ambushes, and sudden firefights do not afford time for soldiers to insert military issued hearing protection. (Courtesy of the U.S. Department of Defense)

Often, initial examination of hearing is made on the basis of a complaint of tinnitus alone. In patients with an acoustic trauma notch, the tinnitus is often described as a pure tone and can be matched to frequencies in the 3000 to 6000 Hz range. Many such patients are unaware of the existence of hearing loss and may even deny it. By the time progression of the impairment has been demonstrated to patients, their communicative difficulties have worsened considerably. The persuasiveness and tact of the audiologist in counseling such patients is of paramount importance.

Lovers of loud music are enthralled by the introduction of the earbuds that are used with iPods and MP3 players. Their improved comfort and sound quality encourage the wearers to increase the sound output of the devices to enhance the personal enjoyment of music. Not only are preferred listening levels higher when earbuds are used, levels of background noise interfere with music reception through earbuds more than through over-the-ear headphones, consequently causing users to seek even higher volume levels (Hodgetts, Rieger, & Szarko, 2007). They are often used by joggers or those working out on gym equipment whose physical stress helps to mask the danger of the increased sound intensity. The fact that the earbuds are pressed into the external auditory canal, thereby decreasing the air volume between them and the tympanic membrane, can increase the SPL of the signal as much as 9 dB over the more-traditional receivers. The ensuing hearing losses often resemble the audiometric features seen in patients whose losses are attributed to aging. The increased damage risk from these devices mandates greater cautionary efforts by hearing healthcare professionals regarding the use of these devices. While research suggests that MP3 listening levels may not be as great a concern for an adult-professional population, routine, long-term use levels are not clearly documented among younger listeners (Hodgetts et al., 2007).

There is hope that one day noise-induced hearing loss may be prevented or even reversed with the proper use of nutrition or medications. The U.S. Navy, with continued funding through the U.S. Department of Defense, continues research on a “hearing pill” containing antioxidants that may positively affect the cochlea. Only time will tell whether this exciting possibility will come to fruition.

There is increasing evidence that noise has other adverse effects besides hearing loss. Noise may play a role in increased anxiety levels, loss of the ability to concentrate, higher divorce rates, greater incidence of illness, and loss of sleep. The ongoing search for U.S. energy independence has led to the development of wind farms across the country (Figure 11.14). While insufficient to damage hearing, the wind turbine noise has been found to be more disturbing than comparably loud transportation noise or industrial noise possibly due to the rhythmic “swishing” noise and the fact that it continues unabated through the night (Pedersen, van den Berg, Bakker, & Bouma, 2009). These ongoing sounds can result in sleep deprivation and subsequent health problems for nearby residents. Additional research has looked at the possible acoustic effects of land-based and off-shore wind farms on wildlife on land and in the sea and air. According to Hempton and Grossman (2009), there is no place left on earth that is free of human-generated noise 100% of the time. Clearly humans’ noise imprint on the world around them is pervasive.

Radiation-Induced Hearing Loss

The use of radiotherapy for the treatment of brain tumors and head and neck cancers can adversely affect any of the auditory structures from the external auditory meatus through the more central auditory pathways. The majority of radiation-induced conductive hearing losses arising from acute complications to the middle-ear system and occurring in up to 40% of patients (Jereczek-Fossa,



FIGURE 11.14 Low-frequency noise accompanied by a perceived “swishing” sound generated by wind turbines may result in sleep deprivation and accompanying health problems for nearby residents. (Courtesy of Lisa A. Miller)

Zarowski, Milani, & Orecchia, 2003) are not permanent. However, nearly one-third of patients whose radiotherapy extends to the cochlea experience permanent sensory hearing loss. The combined use of radiation and chemotherapy place a patient at higher risk for hearing loss. Patients scheduled to undergo radiation should have a pre-radiation baseline auditory assessment with a repeat evaluation at the conclusion of radiotherapy. Given the delayed onset of radiation-induced hearing loss and its documented progression, regular monitoring of hearing status is essential. Audiological management of radiation-induced hearing loss is complicated by the fact that speech recognition can be significantly poorer than would be predicted by the pure-tone hearing loss (Bass & White, 2008).

Cochlear Hearing Loss Following Surgical Complications

There are times when even the best middle-ear surgeon not only fails to improve hearing with corrective surgery but, in fact, makes it worse. Many otologists estimate that a cochlear hearing loss following stapedectomy is probable in 1 or 2% of those operated on. The odds appear very good, except, of course, for the unfortunate few.

An early practice to ensure mobility during stapedectomy was to palpate the ossicular chain to check for a light reflex on the round window. This is no longer done because it has been found to generate traveling waves of amplitude greater than most environmental sounds that can cause cochlear damage.

Excessive bleeding, or other surgical complications, may account for some cases of cochlear hearing loss following middle-ear surgery, but some cases of even total hearing loss in the operated ear cannot be related to any specific cause. Some technically perfect operations are also followed by total deafness. Evidently, for specific physiological reasons, some patients do not tolerate the surgery well. It is to this group that the term “fragile ears” has been assigned, and it is unfortunate that these cases cannot be predicted preoperatively. Common complications of middle-ear surgery include transitory vertigo and alterations in the sense of taste.

Sudden Idiopathic Sensory/Neural Hearing Loss

Sudden idiopathic sensory/neural hearing loss (SISNHL) refers to a hearing loss, usually unilateral, that may develop over the course of a few days or occur seemingly instantaneously, with many patients claiming that they awoke from sleep in the morning to find that their hearing had changed. Generally, a SISNHL is defined as a decrease of at least 30 dB over at least three octaves within a period no greater than three days (Zadeh, Storper, & Spitzer, 2003). Although a number of etiologies have been suggested, they break down into broad categories to include autoimmune diseases, viral or other infections, rupture of the basilar membrane, vascular disorders, tumors, or other neurological disorders. A viral origin may be more suspect if respiratory infection has preceded the loss. While such hearing losses may occur among patients of any age, they are by far most frequent in the adult population.

The nutrition of the cochlea is supplied by the stria vascularis, which is fed by the internal auditory artery, with no collateral blood supply. If a spasm occurs in that artery, total unilateral deafness may result, although the sustained loss may be substantially less for some individuals. A sudden loss of hearing should always be treated as a medical emergency, with diagnosis including a number of blood tests, magnetic resonance imaging, and neurological testing. Therapy is often directed at vasodilation. The sooner therapy is instituted following the onset of symptoms the better is the prognosis for complete recovery.

21. A sudden loss of hearing should be considered a _____.

A relatively new procedure has shown to be beneficial in many cases. A myringostomy is performed and a cylindrical wick is threaded through the PE tube with one end of the wick positioned against the round window membrane. The patient applies steroid drops to the external ear canal, which are drawn through the wick by capillary action and delivered to the inner ear via absorption through the round window. This approach to the administration of steroids for the treatment of sudden idiopathic hearing loss permits the delivery of relatively high concentrations of the medicine, simultaneously minimizing the systemic side effects often observed when these medications are taken orally (Silverstein, Thompson, Rosenberg, Brown, & Light, 2004). The self-administration of the drops significantly reduces the number of physician visits required if medication is administered through transtympanic injections.

If **vasospasm** is suspected as an underlying cause of the hearing loss, treatment often includes immediate hospitalization, with intravenous administration of the appropriate medications. At times, hearing recovery is complete. Vestibular symptoms, such as vertigo and nausea, as well as the often-accompanying tinnitus, may also abate. In some patients, symptoms disappear spontaneously, whereas in others they persist in the form of severe or total unilateral hearing loss.

Ménière's Disease

Another cause of sudden unilateral hearing loss is **Ménière's disease**⁵. The seat of the difficulty lies within the labyrinth of the inner ear. In a normal inner ear, the endolymph is maintained at a constant volume and contains specific concentrations of chloride, sodium, potassium, and other electrolytes, which allows the structures to function normally.

The disorder is characterized by sudden attacks of vertigo, tinnitus, vomiting, and unilateral hearing loss. Although usually unilateral, bilateral Ménière's disease has been observed in 5 to 10% of the studied cases of aural vertigo. Many patients describe the onset of symptoms in the same way. The difficulty may begin with a sensation of fullness in one ear, followed by a low-frequency roaring tinnitus, hearing loss with great difficulty in speech recognition, the sensation of violent turning or whirling in space, and vomiting. Although these may be considered the classic symptoms associated with Ménière's disease, not all symptoms will be present in each case. Indeed, some may have what has come to be known as cochlear Ménière's disease, which may be characterized solely by fluctuating and progressive sensory hearing loss and possible aural fullness accompanying a sudden drop in hearing. Similarly, a second subcategory known as vestibular Ménière's disease may present solely with spells of vertigo with no change in hearing. The symptom of aural fullness helps differentiate this condition from vestibular **neuritis** (Pulec, 1996), or inflammation of the auditory nerve. The qualifiers of "cochlear" or "vestibular" are dropped if more inclusive symptoms of Ménière's disease develop subsequently.

Ménière's disease may occur as a result of a blow to the head, infection, degeneration of the inner ear, allergy, or (in rare circumstances) a tumor. In many cases the cause is entirely undetermined. Many authorities believe that it is caused by endolymphatic hydrops, the oversecretion or underabsorption of endolymph. As the fluid pressure builds in the cochlear duct, the pressure on the hair cells produces the tinnitus and hearing loss. If the pressure builds sufficiently, the vestibular apparatus becomes overstimulated, and vertigo ensues. According to Lawrence (1969), excessive endolymphatic pressure alone could not alter the function of the inner ear unless the metabolic or ionic balances were disturbed, as by a rupture of Reissner's membrane. In earlier times treatment was designed to limit fluid intake and retention through diuretic drugs, but the opposite approach is taken today, assuring that the patient has adequate fluid ingestion. Alcohol, smoking, and caffeine (in the forms of chocolate, cola drinks, coffee and tea) all tend to increase symptoms.

Sedatives, tranquilizers, and vestibular suppressants have all been used. Reports on the success rates of different therapies vary in the medical literature; some have even been described as placebo effects. More recently, wicks placed through a PE tube as described earlier for treatment of sudden idiopathic sensory/neural hearing loss have been used to reduce symptoms of vertigo related to Ménière's disease. Anxiety and allergic factors have been considered as causes of Ménière's disease, which affects more men than women and rarely affects children. Other causes may be trauma, surgery, syphilis, hypothyroidism, and low blood sugar.

Ménière's disease may be extremely handicapping. The paroxysmal (sudden, without warning) attacks of vertigo may interfere with driving an automobile, or even with performing one's job. The disease has been called the "labyrinthine storm," because of the sudden and dramatic appearance of symptoms; it is characterized by remissions and exacerbations. Cases of bilateral hearing loss due to Ménière's disease are helped best with multimemory hearing aids, which offer more than one pattern of amplification to address fluctuating hearing loss.

Surgical approaches to Ménière's disease are often aimed at decompressing the endolymphatic sac or draining the excessive endolymph by inserting a shunt into spaces in the skull so that the fluid can be excreted along with cerebrospinal fluid. Ultrasonic and freezing procedures have also been used. In extreme cases, the entire labyrinth has been surgically destroyed or the auditory nerve severed to alleviate the vertigo and tinnitus. Even such dramatic steps as these are not always entirely successful. Audiological findings in Ménière's disease are shown in Figures 11.15 through 11.18. Specific diagnosis of this condition can often be accomplished with electrocochleography (Ferraro, 1992).

22. A condition sometimes referred to as a "labyrinthine storm" is _____.

Semicircular Canal Dehiscence Syndrome (SCDS)

Also known as **superior canal dehiscence syndrome** because the superior semicircular canal is much more frequently affected than the posterior canal, this disorder can mimic the symptoms of other otologic pathologies and be easily misdiagnosed. Due to its symptoms of dizziness, vertigo, and disequilibrium, SCDS has frequently been misdiagnosed as a peripheral vestibular disorder. In addition to vestibular symptoms, patients with SCDS may present with complaints often associated with a patulous eustachian tube such as a "blocked" sensation in the ear or an echo sensation when talking, known as autophony. SCDS is created by a thinning or weakening of the bone that covers the superior semicircular canal, essentially resulting in a "third window" in the labyrinthine system. Symptoms characteristic of SCDS are induced by intense sounds or change in middle-ear pressure. Typical ENG evaluation reveals no objective findings. Routine audiometrics typically reveal a low-frequency conductive hearing loss with normal tympanometry and present acoustic reflexes. The muscle reflex of the vestibular-evoked myogenic potential (VEMP) is highly sensitive and specific for SCDS, possibly even more so than the results of CT scans (Zhou, Gopen, & Poe, 2007).

Autoimmune Inner-Ear Disease (AIED)

Autoimmune diseases are inflammatory conditions that occur when the immune system causes the body to attack its own tissues as it fails to distinguish them from bacteria, viruses, or cells from other organisms. **Autoimmune inner-ear disease (AIED)** specifically attacks the inner ear,

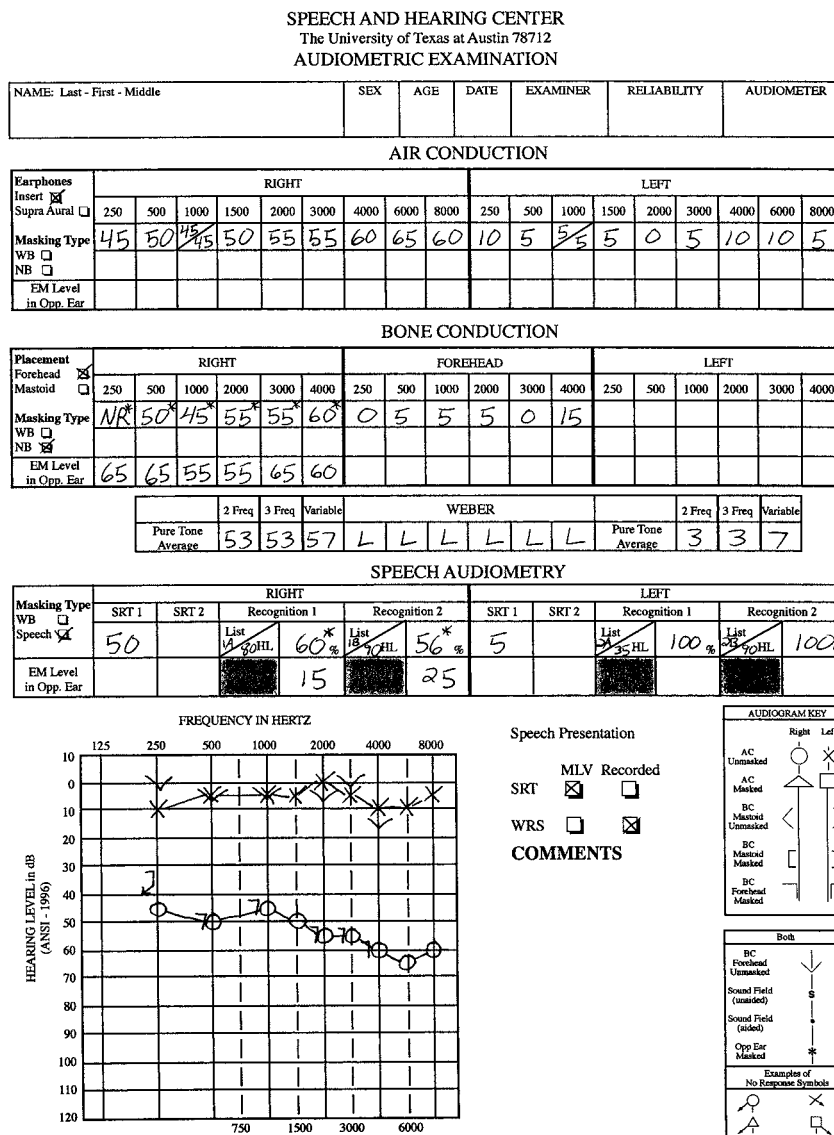


FIGURE 11.15 Audiogram showing a unilateral (right) sensory/neural hearing loss observed in a patient with Ménière's disease. Word recognition is impaired in the right ear. Even with the larger interaural attenuation with insert receivers, masking for WRS is required for speech audiometrics at lower sensation levels.

often resulting in the classical clinical presentation of a bilateral fluctuating and progressive sensory hearing loss, which may occur over several months. Tinnitus, aural fullness, and vertigo may accompany this potentially reversible inner-ear syndrome. The prevalence of AIED is believed to be quite low; however, a significant percentage of bilateral symptoms in Ménière's disease patients may be due to AIED. As in the treatment of sudden idiopathic sensory/neural hearing loss, steroids can be administered via a wick for absorption into the inner ear through the round window.

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IMMITTANCE

NAME Last - First - Middle	SEX	AGE	DATE	EXAMINER	INSTRUMENT

ACOUSTIC REFLEXES

Frequency (Hz)	RIGHT				LEFT			
	500	1000	2000	4000	500	1000	2000	4000
Ipsilateral (Probe same)		90	90			95	100	
Contralateral (Probe opposite)	95	90	100	100	85	85	90	95
Audiometric Threshold	50	45	55	60	5	5	0	10
Reflex SL	45	45	45	40	80	80	90	85
Decay Time (Seconds)	10 ⁺	10 ⁺			10 ⁺	10 ⁺		

STATIC COMPLIANCE

Tymp. Width	M.E. Pressure	RIGHT			Tymp. Width	M.E. Pressure	LEFT			C _a = C _r - C _i
		C _r Volume	C _i	C Compliance			C _r Volume	C _i	C Compliance	
22	0	.40	1.4	1.0	24	0	.45	1.2	.75	

TYMPANOGRAMS

RIGHT

LEFT

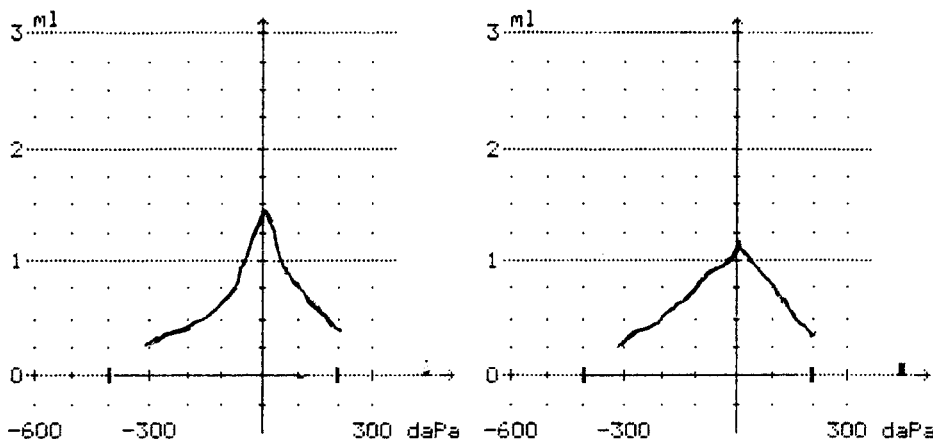
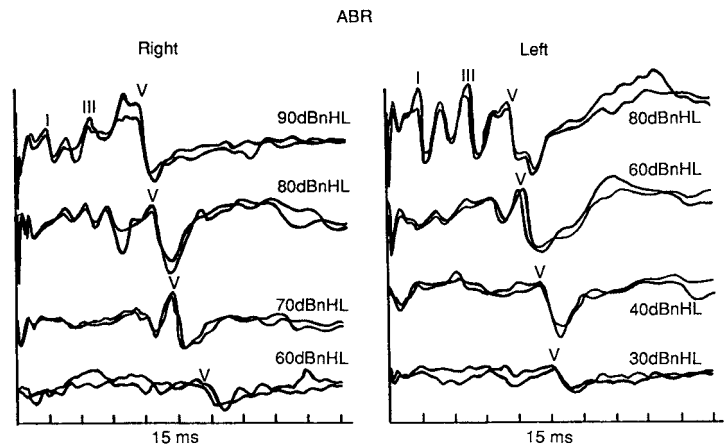


FIGURE 11.16 Results on immittance for the patient with Ménière's disease illustrated in Figure 11.15. The tympanogram is normal for both ears but shows a lower point of maximum compliance on the left ear because of increased pressure in the inner ear. Static compliance is normal for both ears but lower in the left ear than in the right ear. Tympanometric width is normal for both ears. The sensation level of the acoustic reflex is reduced in the right ear, suggesting a lesion of the cochlea.

Head Trauma

Often when a hearing loss is directly related to a head injury, the audiogram is quite similar to those typical of acoustic trauma, showing a "notch" in the 3000 to 6000 Hz range. In addition to damage to the tympanic membrane and middle-ear mechanism, the structures of the inner ear may be torn, stretched, or deteriorated from the loss of oxygen following hemorrhage. If a fracture line runs through the cochlea, the resulting hearing loss will be severe to profound and may

FIGURE 11.17 Results of auditory brainstem response testing on the patient with a cochlear hearing loss (Ménière's disease) in the right ear (see Figure 11.15). Absolute latencies are shown in Figure 11.18.



be total. External and/or internal hair cells may be lost, and the organ of Corti may be flattened or destroyed. Trauma to the skull may also result in complications such as otitis media or meningitis, which may themselves be the cause of a hearing loss. Hearing loss may result from head trauma, even without fracture, if there is a contusion of the cochlea, or if a strong pressure wave is conducted through the skull to the cochlea (Schuknecht, 1993). This may be ipsilateral or contralateral to the skull insult.

Head injuries, acoustic trauma, diving accidents, or overexertion may cause rupture of the round window membrane, or a fistula of the oval window with a perilymph leak into the middle ear. When there is the possibility of a fluid leak, the fistula test, using an immittance meter as described in Chapter 6, can be of great assistance in medical diagnosis.

Presbycusis

The caseload of any audiology clinic will include a large number of patients who have no contributing etiological factors to hearing loss except advancing age. It would be inaccurate to assume that lesions in **presbycusis** (hearing loss due to aging) are restricted to the cochlea, regardless of the relationship to noise exposure mentioned earlier. The aging process produces alterations in many areas of the auditory system, including the tympanic membrane, ossicular chain, cochlear windows, and central auditory nervous system. There is probably some relationship to general oxygen deficiency caused by arteriosclerosis. A precise definition of the age at which presbycusis begins is lacking in the literature, but it should be expected in men by the early 60s and women by the late 60s, all other factors being equal. It is possible that the hearing mechanism begins to deteriorate slowly at birth.

A common characteristic of presbycusis is significant difficulty in speech recognition, which Gaeth (1948) has called **phonemic regression**. Many older people report that they often understand speech better when people speak slowly than when they speak loudly. A number of "typical" presbycusis audiometric contours have been suggested.

The classical work on presbycusis is by Schuknecht (1993), who defined four different, but overlapping, causes of this hearing loss:

1. *Sensory presbycusis*. This sensory loss is produced by a loss of outer hair cells and supporting cells in the basal turn of the cochlea. The audiogram shows a greater hearing loss in the higher frequencies.
2. *Neural presbycusis*. Loss of neurons in the cochlea causes poor speech recognition. The audiogram may be generally flat or slightly poorer in the higher frequencies.

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NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	INSTRUMENT

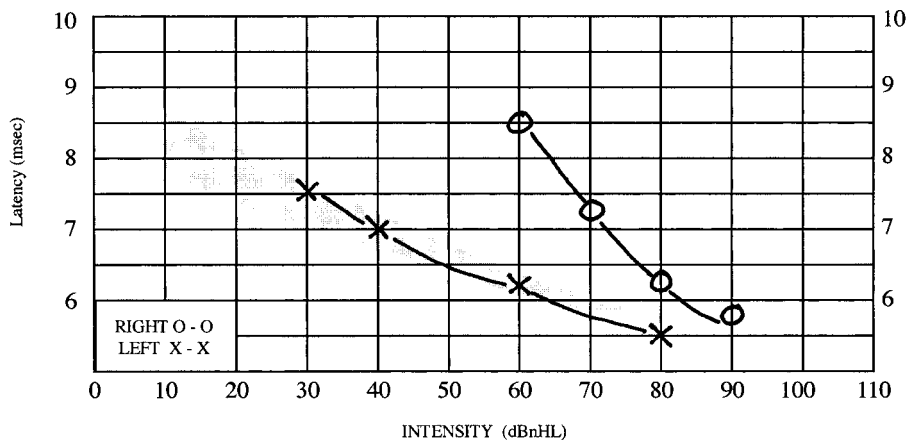
OTOACOUSTIC EMISSIONS
(Present or Absent)

☒ TEOAE Level 50 dB Peak SPL
☐ DPOAE Level F₁ ___ F₂ ___

Right					Left				
500	1000	2000	4000	6000	500	1000	2000	4000	6000
A	A	A	A	A	P	P	P	P	P

AUDITORY BRAINSTEM RESPONSE

ABR WAVE V LATENCY-INTENSITY FUNCTION



EAR	nHL		Absolute Latency (ms)			Interpeak Latency (ms)			Latency Change w/ Increased Rate	
	dB HL	Click Rate	I	III	V	I-III	III-V	I-V	V	Click Rate
RIGHT	90	33.1	1.6	3.75	5.8	2.15	2.05	4.2		
LEFT	80	33.1	1.52	3.7	5.6	2.18	1.9	4.08		
Interaural Differences										

Amplitude Ratio (V same or > I) R NL L NL
 Estimated Air Conduction Threshold R ≤60 L ≤30
 Estimated Bone Conduction Threshold R ____ L ____

FIGURE 11.18 Latency-intensity functions for Wave V derived from the auditory brainstem response tracings shown in Figure 11.17 on the patient with a unilateral (right) cochlear hearing loss (see Figure 11.15). The latencies are normal for the left ear and increased for the right ear, primarily at lower intensities. Otoacoustic emissions are absent in the affected ear.

3. *Strial presbycusis*. Atrophy of the stria vascularis in the middle and apical turns of the cochlea produce a fairly flat audiogram. Speech recognition is reasonably good.
4. *Cochlear conductive presbycusis*. Impaired mobility of the cochlear partitions produces a sensory hearing loss that is primarily mechanical in nature.

Gates, Mills, Nam, D'Agostino, and Rubel (2002) investigated adult hearing loss using distortion-product otoacoustic emissions to help determine the root cause of presbycusis. Contrary to popular theory that age-related hearing loss is primarily a function of decreased outer hair cell activity, their findings indicate stria degeneration may be the primary contributor to presbycusis.

Some gender effects have been noted regarding the audiometric configuration of presbycusic patients. Jerger, Chmiel, Stach, and Spretnjak (1993) surveyed a large number of audiograms over a 50-year period and found that elderly males tend to show greater hearing loss above 1000 Hz, whereas elderly females have poorer sensitivity below 1000 Hz, even when accounting for such environmental factors as noise exposure. This same finding of a greater prevalence of sloping audiometric configurations for males than females has been reported within a non-elderly population as well (Ciletti & Flamme, 2009). Possible explanations for this gender difference are the greater presence of cardiovascular disease in elderly females and the increase in variety and amounts of noise exposures among men.

Approximately 25% of adults in the age range of 45 to 64 years and 40% of those over 65 have some degree of hearing loss (Glass, 1990). Hearing loss in this context is defined as a handicap in social, emotional, vocational, and psychological areas (ASHA, 1992). Efforts are being made to screen elderly citizens for hearing loss, in ways similar to screening infants and school children, in order to identify problems and seek solutions as early as possible. Such screening tests must be effective, high in sensitivity and specificity, and yield a high predictive value.

Screening instruments are available that can be used effectively by primary-care physicians to identify their patients with sufficient hearing loss who should consider amplification with hearing aids. These instruments can deliver pure tones at 500, 1000, 2000, and 4000 Hz at 40 dB HL. Since the devices are easy to use and quickly become cost-effective, it may soon be possible for audiologists to receive referrals so that they may serve adults earlier in the development of their hearing problems. Widespread definitive programs for screening elderly adults may be on the horizon.

23. Hearing loss caused by the aging process is called _____.

EVOLVING CASE STUDIES

Chapter 11 is on the subject of the inner ear so you are asked here to look at the two cases we have been following that probably have their lesion sites in this area, Cases 2 and 4. The term "sensory/neural" is actually a broad one because it suggests that a given hearing loss is either sensory (in the inner ear) or neural (on the auditory nerve), although it may, of course, be both. The former is the more usual lesion site. Discussion below will briefly review what we know about these two cases to this point. Before reading the following entries, remember that following Chapter 7 you were asked to predict the results for acoustic immittance, acoustic reflex thresholds (ART), otoacoustic emissions (OAE), and auditory brain-stem response (ABR) measures. In addition, based on what you know so far of these two cases and the tests you have studied, predict, as far as can be determined, the area causing the hearing loss in these two cases (cochlear [sensory] or retrocochlear (neural, "beyond" the cochlea). Some of the

other site-of-lesion tests described in Chapter 7 will not be discussed here, but you may feel free to conjecture about the possible outcomes on those tests.

Both of these cases will be revisited in Chapters 14 and 15 as we begin to look at the steps that must be taken toward the successful audiological treatment of these hearing losses.

Case Study 2: Sensory/Neural Hearing Loss

As presented in the Case Studies discussion in Chapter 4, this 76-year-old male patient has a moderate loss similar to Figure 4.14. Given no air-bone gaps greater than 10 dB in this audiogram (and presumably in the audiogram you had predicted following reading of Chapter 4), this patient clearly has a sensory/neural hearing loss. As was stated following Chapter 5 (and as you may have predicted at that time), speech-recognition abilities would be somewhat reduced with this loss. The probability is that the tympanograms will be normal (Type A) with acoustic reflex thresholds, ipsilateral and contralateral, occurring at low sensation levels. OAEs will probably be absent and if ABR testing were to be completed, the latency-intensity functions for Wave V in both ears would resemble those shown for the right ear in Figure 12.16. All test results up to this point are consistent with a cochlear site of lesion or sensory hearing loss.

Case Study 4: Pediatric Patient

As presented in the discussion of this case in Chapter 8, play audiometric testing with this 3-year-old girl revealed a severe loss by air conduction of 70 to 90 dB with essentially absent bone-conduction responses. Limited language abilities for this little girl made it impossible to obtain meaningful speech-recognition test results. Tympanometry was reported to be normal, and, as expected, acoustic reflexes were absent, as were OAEs and responses to ABR. The Auditory Steady State Response was consistent with the pure-tone findings. Since most, but certainly not all, sensory/neural hearing losses in small children are caused by damage to the cochlea, it is assumed that this is the case here, but exceptions do occur, and the alert audiologist is always on the lookout for this. Given this documented hearing loss, if an otologic consult has not been arranged previously, this referral should be coordinated through the pediatrician to ensure a full medical workup to see if etiology can be determined.

Summary

The inner ear is a fluid-filled space, interfaced between the middle ear and the auditory nerve. It acts as a device to convert sound into a form of electrochemical energy that transmits information to the brain about the frequency, intensity, and phase of sound waves. The vestibular portion of the inner ear provides the brain with data concerning the position and movement of the body.

When the cochlear portion of the inner ear becomes abnormal, the result is a combination of sensory hearing loss and dysacusis. Bone-conduction and air-conduction results essentially interweave on the audiogram, and word recognition generally becomes poorer in direct relation to the amount of hearing loss. Results on tympanometry and static immittance in the plane of the tympanic membrane are usually within normal limits, unless the sensory loss has a superimposed conductive component, resulting in a mixed hearing loss. Acoustic reflex thresholds are expected at low sensation levels. In pure cochlear hearing losses, the latency-intensity functions obtained

from ABR testing are rather steep, showing longer latencies close to threshold. If the outer hair cells are damaged, causing more than a mild hearing loss, otoacoustic emissions will be absent.

If any of the behavioral site-of-lesion tests discussed in Chapter 7 are performed, patients with cochlear hearing loss are expected to show high SISI scores and moderate amounts of tone decay (especially in the higher frequencies). Recruitment of loudness can usually be found, which often complicates auditory rehabilitation.

Habilitation or rehabilitation of patients with sensory hearing losses of cochlear origin is considerably more difficult than for patients with conductive lesions. Medical or surgical correction is usually obviated by the very nature of the disorder; however, there are several important exceptions to this. Combinations of harmonic and frequency distortion and loudness recruitment often make the use of hearing aids difficult but not impossible. Auditory rehabilitation of patients with cochlear disorders is of special concern to audiologists.

REVIEW TABLE 11.1 Common Causes of Cochlear Hearing Loss According to Age at Onset

<i>Prenatal</i>	<i>Childhood</i>	<i>Adulthood (All of column 2, plus)</i>
Anoxia	Birth trauma	Autoimmune inner-ear disease
Heredity	Drugs	Labyrinthitis
Rh factor	Head trauma	Ménière's disease
Toxemia of pregnancy	High fever	Otosclerosis
Trauma	Kidney infection	Presbycusis
Viral infection (maternal)	Noise	Vasospasm
	Otitis media	
	Prematurity	
	Surgery (middle ear)	
	Systemic illness	
	Venereal disease	
	Viral infection	

Related Websites

A number of websites that may be of interest to the inquisitive reader are related to topics in this chapter. For further information on a variety of syndromes, the reader is directed to the following:

- Alport Syndrome,
www.alportsyndrome.org/alport_syndrome.html
<http://emedicine.medscape.com/article/981126-overview>
- CHARGE Syndrome,
www.chargesyndrome.org/about-charge.asp
<http://emedicine.medscape.com/article/942350-overview>
- Down Syndrome,
www.intellectualdisability.info/complex_disability/hearing_ds.htm
- Klippel-Feil Syndrome,
<http://emedicine.medscape.com/article/1264848-overview>
- Pierre Robin Syndrome,
<http://emedicine.medscape.com/article/844143-overview>
- Treacher Collins Syndrome,
www.cleftline.org/publications/treacher_collins
- Usher Syndrome,
www.nidcd.nih.gov/health/hearing/usher.asp
www.boystownhospital.org/Usher/information.asp
- Waardenburg Syndrome,
<http://emedicine.medscape.com/article/950277-overview>

For information on some of the other causes of sensory/neural hearing loss:

- Autoimmune Hearing Loss,
www.american-hearing.org/disorders/autoimmune/autoimmune.html
- Genetics and Hearing Loss,
www.cdc.gov/ncbddd/ehdi/genetics.html
- Noise-Induced Hearing Loss,
www.nidcd.nih.gov/health/hearing/noise.asp

www.american-hearing.org/disorders/hearing/noise_induced.html

- Ototoxicity,
www.merck.com/mmpe/sec08/ch086/ch086d.html

For information on balance problems and balance evaluation:

- Balance evaluation,

<http://emedicine.medscape.com/article/836028-overview>

- Benign Paroxysmal Positional Vertigo,
www.merck.com/mmpe/sec08/ch086/ch086c.html
- Ménière's Disease,
www.dizziness-and-balance.com/disorders/menieres/menieres.html

Study Questions

1. List from memory as many parts of the inner ear as you can, separating them into auditory and vestibular categories.
2. List some disorders of the inner ear. Break them down according to age of onset.
3. Draw typical audiograms from the preceding list. Hypothesize the results on such tests as SRT, WRS, ABR, OAE, acoustic immittance, and tone decay.
4. Describe the difference between autosomal recessive and autosomal dominant hearing losses.
5. What is the difference between an afferent and efferent sensory system?
6. Discuss the trade-off between sound intensity and the length of exposure time in relation to hazardous noise levels.

Suggested Readings

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Toriello, H. V., Reardan, W., & Gorlin, R. J. (2004). *Hereditary hearing loss and its syndromes* (2nd ed.). New York: Oxford University Press.

Endnotes

1. For Ernst Reissner, German anatomist, 1824–1878.
2. For Alfonso Corti, Italian anatomist, 1822–1888.
3. Hermann Ludwig Ferdinand Helmholtz, German physicist and physiologist, 1821–1894.
4. Georg von Békésy, Hungarian physicist and Nobel Prize winner, 1899–1972.
5. Named for Prosper Ménière, French physician, 1799–1862, who first described this syndrome.

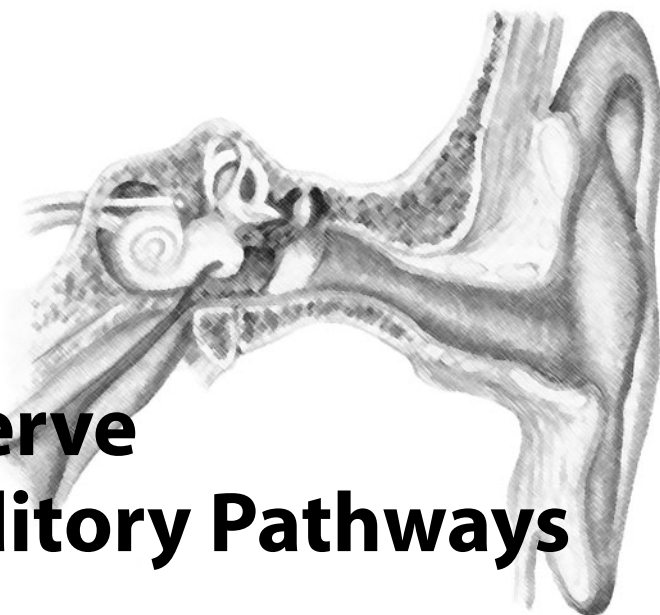
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CHAPTER 12



The Auditory Nerve and Central Auditory Pathways

THE PREVIOUS THREE CHAPTERS have been concerned with the propagation and conduction of sound waves through the outer and middle ears and the transduction in the cochlea of these pressure waves into neural activity to be processed by the central auditory system. Because sound is meaningful only if it is perceived, an understanding of its transmission to, and perception by, the brain is essential to the audiologist. Much remains to be learned about how the nervous system transmits, receives, and processes information related to sound.

Diagnosis of disorders of the auditory system from the outer ear through the auditory nerve is best made through the test battery. This battery includes pure-tone and speech audiometry, measurements of acoustic immittance at the tympanic membrane, and measures of ABR and OAE. This chapter's treatment of the anatomy and physiology of the central auditory system is designed mainly to introduce the reader to these processes; it is therefore far from complete. As in the previous chapter, this presentation relies heavily on what has been learned in the foregoing sections of this book. For a deeper understanding of these issues, the reader is encouraged to pursue the suggested readings.

LEARNING OBJECTIVES

The tests described in this chapter for site-of-lesion diagnosis in the brain have met with varying degrees of clinical acceptance and are offered to the new student in diagnostic audiology because they seem to be the most appropriate ones at the time of this writing. Upon the completion of this chapter the reader should be able to

- Provide a general description of the complexities of the central auditory system and the difficulties of diagnosing disorders in the brain.

- Initiate and interpret test procedures for proper diagnosis of auditory disorders beyond the cochlea.
- Discuss management considerations for retrocochlear pathology.

From Cochlea to Auditory Cortex and Back Again

Almost without exception, every anatomical structure on one side of the brain has an identical structure on the opposite side of the brain. For clarity, a block diagram (Figure 12.1), rather than a realistic drawing, is shown to illustrate the auditory pathways. This diagram represents the anatomical arrangement in the system and illustrates the directions of neural impulses and the

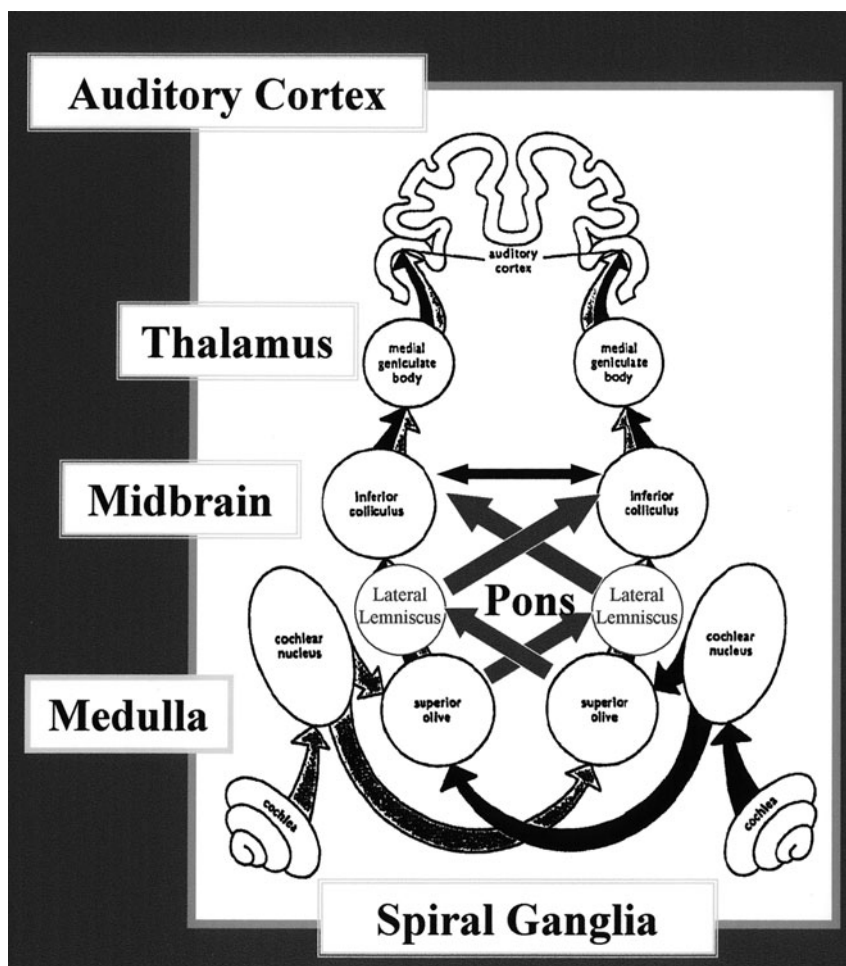


FIGURE 12.1 Ascending auditory pathways. As illustrated, several decussations, or crossover points, beginning at the level of the cochlear nucleus, provide bilateral representation to signals presented to just one ear. (Courtesy of Dr. Chris Matyear as a modification of the figure by Yost & Nielsen, 2000)

primary waystations from cochlea to auditory cortex. A comprehensive review of the anatomy and physiology of the auditory nerve and its waystations is provided by Muziek and Baran (2007).

Nerve fibers pass from the cochlea through the **internal auditory canal**, which begins at the cochlear modiolus and terminates at the base of the brain. The internal auditory canal also carries the vestibular portion of the VIIIth nerve, whose fibers are innervated by the utricle, saccule, and semicircular canals. There are approximately 30,000 nerve fibers in the cochlear portion and 20,000 in the vestibular portion. The auditory portion of the VIIIth nerve actually spirals through the internal auditory canal. The nerve fibers form a cylindrically arranged bundle, or “cable,” with fibers that arise from the basal (high frequencies) turn of the cochlea, forming the outer portion, and fibers from the apical (low frequencies) areas, forming the center, together creating the nerve trunk. In addition to the VIIIth nerve, the internal auditory canal, which runs a distance of approximately 10 mm in adults, also carries the internal auditory artery and fibers of the VIIth (facial) nerve.

1. The internal auditory canal contains _____, _____, _____, and _____.

The **auditory nerve** extends 17 to 19 mm beyond the internal auditory canal, where it attaches to the brainstem, at which the **cerebellum**, **medulla oblongata**, and **pons** join to form the **cerebellopontine angle (CPA)**. At this level, the auditory and vestibular portions of the VIIIth nerve separate. One part of the cochlear bundle descends to the **dorsal cochlear nucleus**, and the other ascends to the **ventral cochlear nucleus**.

As previously mentioned, neurons from the cochlea are arranged in an orderly fashion according to frequency. The arrangement of fibers in the cochlea is repeated in the auditory nerve and central auditory structures, and is said to represent **tonotopic** organization. Tonotopicity is the spatial representation of the frequency layout of the cochlea in retrocochlear structures. The auditory nerve fibers terminate in the cochlear nuclei—basal turn fibers in one area, apical turn fibers in other areas, and so on. The different cell types of the cochlear nucleus react differently to the incoming auditory nerve impulses, thus modifying input to the brain.

The brain is characterized by many **decussations**, or crossover points, that unite symmetrical portions of its two halves. Specialized nerve-fiber bundles called **commissures** unite similar structures on both sides of the brain. The first decussation in the auditory pathways occurs after the cochlear nucleus at the level of the **trapezoid body** of the pons, representing the beginning of bilateral representation of a signal presented to just one ear.

The **superior olivary complex** receives input from both the ipsilateral and contralateral cochlear nuclei. The large number of neural inputs allows the superior olivary complex to sense the direction of a sound source by analyzing small differences in the time or intensity of a sound arriving at the two ears. In addition to its major function as a relay station for neural activity on the way to the cerebral cortex, the superior olivary complex also mediates the reflex activity of the tensor tympani and stapedius muscles of the middle ear. Some of the cells of the superior olive interact with some neurons of the facial nerve. Intense sounds produce activation of certain motor fibers of the facial (VIIth cranial) nerve, which innervate the stapedial branch of this nerve. The decussations at this anatomical point explain the contraction of the stapedius muscles in both middle ears when sound is presented to just one ear. A diagram of the ascending pathways through the superior olivary complex was shown in Figure 7.6 in discussion of the acoustic reflex pathways.

The **lateral lemniscus** provides a major pathway for the transmission of impulses from the ipsilateral lower brainstem. Some fibers terminate in the nucleus of the lateral lemniscus, others course to the contralateral lemniscus, and still others continue to the **inferior colliculus**. The inferior colliculus receives afferent stimulation from both superior olivary complexes. Neurons that connect the inferior colliculus with the next relay station, the **medial geniculate body**,

represent the third or fourth link in the ascending auditory system. A few fibers bypass the inferior colliculus to reach the medial geniculate body directly from the lateral lemniscus.

The medial geniculate body, located in the **thalamus**, is the last subcortical relay station for auditory impulses. Of its three main areas, the ventral division is primarily responsible for auditory information. After this point, nerve fibers fan out as the **auditory radiations** and then ascend to the auditory cortex. Because there are no commissural neurons at the level of the medial geniculate body, no decussations exist there.

The areas of auditory reception are in the **temporal lobes** on both sides of the cerebral cortex in an area called the **superior temporal gyrus** or **Heschl's gyrus**. There is evidence that the selective representation of frequency, observed at specific places in the cochlea, is repeated in the auditory cortex, although to a lesser degree. Apparently, the temporal area is concerned primarily with the frequency characteristics of sound, the **insular** area with the temporal aspects of sound, the **parietal** area with association of sound with past experiences (and because this area has inputs from all sensory modalities, the auditory stimulus is compared or matched with input from other senses), and the frontal area with the memory of sounds.

At one time it was believed that the auditory cortex was the only center for auditory discrimination. It is now known that many discriminations may be mediated subcortically. Perceptions of pitch and loudness can be maintained in animals whose cortices have been surgically removed. Although discrimination of some simple sounds may be retained, the understanding of speech requires at least minimal integrity of the auditory cortex.

The auditory system is generally considered to be a sensory system (like the skin or the eyes). It provides the brain with information transmitted to the cochlea in the form of pressure waves and transduced by the cochlea into neural activity to be sent to the brain. In addition to the **afferent** pathways, the auditory system contains a complex **efferent** system of descending fibers. These descending fibers correspond closely with the ascending fibers and connect the auditory cortex with lower brain centers and with the cochlea. One presumed purpose of this descending system is to provide inhibitory feedback by elevating the thresholds of neurons at lower stations in the auditory tract. It is true, however, that some descending connections have an excitatory function, but their purpose is not clearly understood.

2. Efferent neurons
carry impulses _____
(to or from) the brain
while afferent neurons
carry impulses _____
(to or from) the brain.

Development of the Auditory Nerve and Central Auditory Nervous System

Relatively little information is available on the prenatal development of the VIIIth nerve and central auditory nervous system. Development of the nervous system (neurogenesis) in general is still poorly understood. In humans, the VIIIth nerve begins to form at about the 25th gestational day and appears almost complete at about 45 days. It is probable that the efferent fibers develop later than the afferent fibers. The cochlear and vestibular ganglia appear by the 5th week.

Improved understanding of the embryogenesis and fetogenesis of the central auditory pathways will undoubtedly provide insights into the causes of some types of lesions of the auditory nervous system. It is generally agreed that the entire nervous system forms from the ectoderm.

Summary of the Auditory Pathways

The auditory nerve and central pathways are tremendously complex. The ascending (afferent) system provides stimulation from one ear to both sides of the brain, including the temporal cortex. Descending efferent fibers from each side of the brain provide inhibition to both cochleas.

The waystations in the auditory system perform the complex processing of the incoming nerve impulses. The series of cochlear nucleus, superior olivary complex, lateral lemniscus, inferior colliculus, and medial geniculate body are not simply parts of an elaborate transmission line whereby the coded information of the VIIIth nerve is relayed to the cortex. Recoding and processing of information take place all the way up through the system.

Hearing Loss and the Auditory Nerve and Central Auditory Pathways

Because there are many collateral nerve fibers and so much analysis and reanalysis of an acoustic message as it travels to the higher brain centers, it is said that the auditory pathways provide considerable *intrinsic redundancy*. There are also many forms of *extrinsic redundancy* in speech

3. Many tests for central auditory disorders are designed to reduce _____ redundancy.

messages themselves, such as the usual inclusion of more words than necessary to round out acceptable grammar and syntax. Also, the acoustics of speech offer more frequency information than is absolutely essential for understanding. For example, the average telephone only transmits frequencies between about 300 and 3000 Hz, far less than the frequency range for normal hearers, and yet voices can be clearly understood. People with normal auditory systems rarely appreciate the ease these factors provide in understanding spoken language. Those who are deprived of some intrinsic redundancy may not show much difficulty in discrimination until the speech message has been degraded by noise, distortion, or distraction, limiting the extrinsic redundancy.

Lesions in the conductive portions of the outer and middle ears and the sensory cells of the cochlea result in the loss of hearing sensitivity. The extent of the hearing loss is in direct proportion to the degree of damage. Loss of hearing sensitivity, such as for pure tones, becomes less obvious as disorders occur in the higher centers of the brain. For these reasons, even though site-of-lesion tests may be extremely useful in diagnosing disorders in the more peripheral areas of the central auditory pathways, such as the auditory nerve and cochlear nuclei, these tests frequently fail to identify disease in the higher centers.

Disorders of the Auditory Nerve

Lesions of the auditory nerve result in hearing losses that are classified as sensory/neural. Bone conduction and air conduction interweave on the audiogram, and there is usually little or nothing in the general audiometric configuration that differentiates cochlear from VIIIth nerve disorders. Johnson (1977) points out that in more than 50% of a series of patients with acoustic tumors, consistent audiometric configurations appeared but could not be differentiated from cochlear lesions according to audiometric patterns. In fact, a small percentage of patients with acoustic neuromas will have normal pure-tone audiograms and normal ABR findings (Telian, Kileny, Niparko, Kemink, & Graham, 1989). Two common early symptoms of auditory nerve disorders are tinnitus and high-frequency sensory/neural hearing loss. Whenever cases of unilateral or bilateral sensory/neural hearing loss with different degrees of impairment in each ear occur, alert audiologists suspect the possibility of neural lesions. The philosophy that *all unilateral sensory/neural hearing losses are of neural origin until proved otherwise* is a good one to adopt.

A second symptom of auditory nerve disorders is apparent when there is a discrepancy between the amount of hearing loss and the scores on speech-recognition tests. In most cochlear disorders, as the hearing loss increases, the amount of dysacusis also increases. When difficulties in speech recognition are excessive for the amount of hearing loss for pure tones, a neural lesion is suggested. In some cases of VIIIth nerve disorder, hearing for pure tones is normal in the presence of speech-recognition difficulty. Despite these statements, it must be remembered that, even in cases of neural lesions, patients' speech-recognition scores may be perfectly normal.

Lesions of the VIIIth nerve may occur as a result of disease, irritation, or pressure on the nerve trunk. Etiologies for these include tumor, meningitis, hemorrhage, and trauma. Because the cochlear nerve extends into the brain for a short distance beyond the end of the internal auditory canal, some lesions of this nerve may occur in the canal and some in the cerebellopontine angle.

Tumor of the Auditory Nerve

Most tumors of the auditory nerve are benign and vary in size depending on the age of the patient and the growth characteristics of the **neoplasm**. Usually these tumors arise from sheaths that cover the vestibular branch of the VIIIth nerve. The term usually applied to these tumors is **acoustic neuroma**, although some neuro-otologists believe that the term *acoustic neurinoma* is more descriptive of some growths that arise from the peripheral cells of the nerve. Since most acoustic neuromas arise from the Schwann cells¹ that form the sheath of the vestibular branch of the VIIIth nerve, it has been suggested that the term *vestibular schwannoma* would be most descriptive.

An acoustic neuroma is considered small if it is contained within the internal auditory canal, medium-sized if it extends up to 1 centimeter into the cerebellopontine angle, and large if it extends any farther (Pool, Pava, & Greenfield, 1970). The larger the tumor within the canal, the greater the probability that pressure will cause alterations in the function of the cochlear, vestibular, and facial nerves, as well as the internal auditory artery. The larger the tumor extending into the cerebellopontine angle, the greater the likelihood that the pressure will involve other cranial nerves and the cerebellum, which is the seat of balance and equilibrium in the brain. It is difficult to predict the growth rate of acoustic neuromas, but most increase slowly in size, on the average of 0.11 cm per year (Strasnick, Glasscock, Haynes, McMenomey, & Minor, 1994).

Acoustic neuromas occur in the United States at the rate of about 1 per 100,000 each year. Most cases occur in adults over the age of 30, although naturally there are exceptions. These tumors comprise about 6% of all intracranial tumors, 30% of brainstem tumors and far and away the majority of tumors in the cerebellopontine angle (Kim, Klopfenstein, Porter, & Syms, 2004). About 95% of these tumors are unilateral, and all are thought to be the result of the absence of a tumor-suppressor gene (NIH Consensus Statement, 1991). Acoustic neuromas have been known to occur in both ears, either simultaneously or successively. One disease, **neurofibromatosis (NF)**, or von Recklinghausen disease,² may cause dozens or even hundreds of neuromas in different parts of the body, including the internal auditory canal.

The earlier in their development acoustic neuromas are discovered, the better the chance for successful surgical removal. Audiological examination is very helpful in making an early diagnosis. Most hearing clinics, however, do not see patients with early acoustic neuromas because hearing loss is not a primary concern in the initial stages. As the tumor increases in size, VIIIth nerve symptoms, such as tinnitus, dizziness, hearing loss, and speech-recognition difficulties, become apparent. While the increase in the size of an acoustic neuroma usually shows progressive unilateral hearing loss as the first symptom, it is often accompanied by facial weakness or

numbness and alterations in the senses of taste and vision. If the tumor grows very large, it can cause speech and swallowing difficulties and, eventually, hydrocephalus and death.

Since acoustic neuromas are usually benign, they do their damage by pressing on the brain or other cranial nerves. When these tumors occur within the internal auditory canal, they are called intracranial, and when they are outside the canal they are called extracranial. Decisions on whether to operate depend on a number of variables including the age of the patient and the age at onset of the tumor, its size and precise location, the patient's preference and, of course, the symptomatology.

Modern approaches to removal of acoustic neuromas carry with them lower rates of mortality and morbidity (a fatal outcome vs. the appearance of complications) than do many neurosurgical approaches. A procedure called **Gamma Knife®**, which involves the application of focused beams of gamma radiation, has been used with great success. These rays usually do not destroy the tumor but rather arrest its growth. The rays can be precisely aimed at specific abnormalities and, by not requiring surgical incision, practically eliminate the common risks of infection and complications from general anesthesia and blood transfusion. Usually performed as an outpatient procedure, it allows for treatment of otherwise inaccessible lesions, minimizes damage to surrounding tissue, and is painless, which frees most patients from post-treatment medication.

Although acoustic neuromas usually result in gradually progressive hearing loss, pressure on the internal auditory artery may result in interference with the blood supply to the cochlea and cause sudden hearing loss and/or progressive sensory hearing loss as a result of anoxia in the cochlea. Changes in blood supply to the cochlea may cause cochlear symptoms to appear, such as misleading ABR patterns and complaints of loudness recruitment, possibly resulting in the misdiagnosis of cochlear disease as the primary disorder.

Cranial nerves other than number VIII may be affected as an acoustic tumor increases in size. Symptoms of Vth (trigeminal) nerve involvement include pain and numbness in the face. Occasionally, nerve VI (abducens) becomes compressed, causing double vision (diplopia). VIIth (facial) nerve symptoms include the formation of tears in the eyes; alterations in the sense of taste; and development of facial weakness, spasm, or paralysis. Abnormalities of the facial nerve often result in the loss of the corneal reflex; that is, the patient's eyes may not show the expected reflexive blink when a wisp of cotton is touched to the cornea. Dizziness and blurred vision may

4. The usual term for tumors of the VIIIth cranial nerve is _____.

also occur. The loss of both ipsilateral and contralateral acoustic reflexes may result when measurement is taken with the probe in the ear on the same side as an impaired facial nerve (see Table 7.2 (H)). As the IXth (glossopharyngeal), Xth (vagus), or XIIth (hypoglossal) cranial nerves become involved, difficulty in swallowing (dysphagia) and speaking (dysarthria) may ensue. When the brainstem is compressed as a tumor increases in size, symptoms include coma and eventually death. Audiologists should always consider the possibility of an intracranial tumor when patients present symptoms that include headache, vomiting, lethargy, respiratory distress, and unilateral hearing loss. Figure 12.2 shows an audiogram illustrating a high-frequency hearing loss. The findings of tests for the patient illustrated are typical of acoustic neuroma, but in any given case one or more of these results may differ from what is expected. Auditory nerve lesions cannot be diagnosed on the bases of a "typical" audiometric configuration.

Proper audiological diagnosis consists of utilizing information from a battery of tests. As shown in Figure 12.2, speech-recognition scores are poor in the impaired ear. Acoustic reflexes are absent in many cases (Figure 12.3), even at very high stimulus levels (Anderson, Barr, &

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AUDIOMETRIC EXAMINATION

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	AUDIOMETER

AIR CONDUCTION

Earphones Insert ☒ Supra Aural ☐	RIGHT										LEFT									
	250	500	1000	1500	2000	3000	4000	6000	8000	250	500	1000	1500	2000	3000	4000	6000	8000		
Masking Type WB ☐ NB ☐	0	5	10	5	5	10	5	5	5	10	15	15	20	30	35	60	55	60		
EM Level in Opp. Ear																				

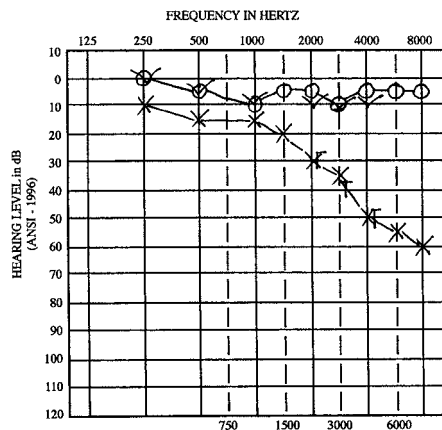
BONE CONDUCTION

Placement Forehead ☒ Mastoid ☐	RIGHT						FOREHEAD						LEFT						
	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	250	500	1000	2000	3000	4000	
Masking Type WB ☐ NB ☒							0	5	10	10	10	10					30	40	50
EM Level in Opp. Ear																	30	45	50

	2 Freq	3 Freq	Variable	WEBER						2 Freq	3 Freq	Variable
Pure Tone Average	5	7	7	R	R	M	R	R	R	15	20	32

SPEECH AUDIOMETRY

Masking Type WB ☐ Speech ☒	RIGHT				LEFT			
	SRT 1	SRT 2	Recognition 1	Recognition 2	SRT 1	SRT 2	Recognition 1	Recognition 2
	5		List 1 55HL 100%	List 2 34HL 100%	20		List 1 25HL 64%	List 2 40HL 56%
EM Level in Opp. Ear				30				20



Speech Presentation

MLV Recorded
SRT ☒ ☐
WRS ☐ ☒

COMMENTS

AUDIODEGRAM KEY

Right	Left
AC Unmasked	○
AC Masked	×
BC Mastoid Unmasked	<
BC Mastoid Masked	>
BC Forehead Unmasked	[
BC Forehead Masked	]

Both

BC Forehead Unmasked	↓
Sound Field (unmasked)	○
Sound Field (masked)	×
Opp. Ear Masked	*

Examples of No Response Symbols

○	×
○	×

FIGURE 12.2 Audiogram exemplifying an early left acoustic neuroma. Although the hearing loss in the left ear is mild, word recognition is quite poor. Naturally, proper masking is essential in this case, especially for bone-conduction and speech-recognition testing.

Wedenberg, 1969). If an acoustic reflex can be obtained, the time required for its amplitude to decay by 50% is markedly reduced in the low frequencies (less than 10 seconds). In 10 cases of acoustic neuroma described by Anderson and colleagues, the acoustic reflex half-life was less than 3 seconds for frequencies at and below 1000 Hz. Jerger, Oliver, and Jenkins (1987) reported on several cases of acoustic tumors in which the most dramatic finding was the decrease in acoustic reflex amplitude when the eliciting stimulus was presented to the ear on the affected side. ABR latencies in the affected ear are markedly increased (Figures 12.4 and 12.5), and otoacoustic emissions are present, since there is apparently no damage to the cochlea (Figure 12.5). Valente, Peterein, Goebel, and Neely (1995) found that elevated or absent acoustic reflexes and abnormal findings on ABR testing were the best tests of correct diagnosis of acoustic neuromas.

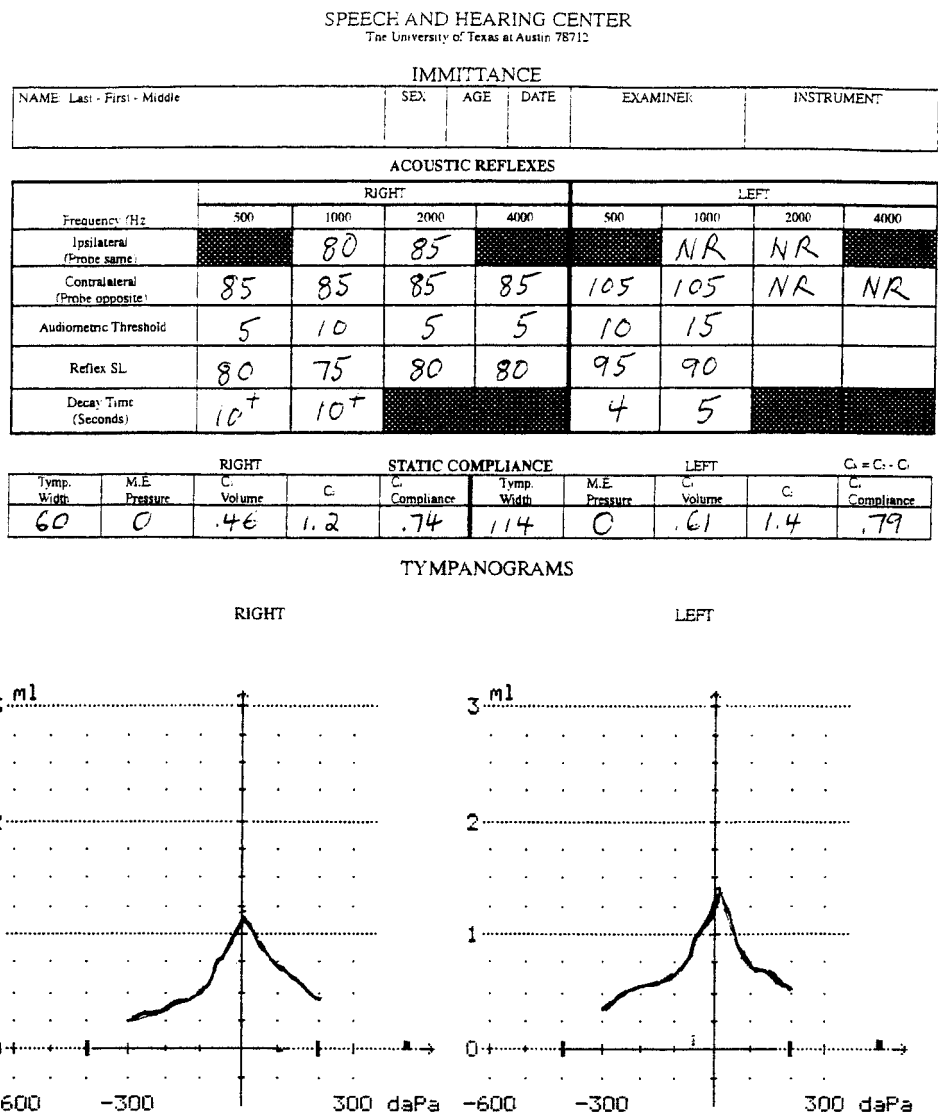


FIGURE 12.3 Results on immittance measures for the theoretical patient illustrated in Figure 12.2. Tympanograms and static compliance are normal for both ears. The acoustic reflexes are normal when the tone is presented to the right (normal) ear. Reflex thresholds are elevated when tones are presented to the left ear (acoustic neuroma) in the low frequencies and absent for the higher frequencies. Reflex decay time is very rapid in the left ear in the low frequencies, with no decay in the right ear.

5. It is likely that a patient with an acoustic neuroma will show _____ (normal or abnormal) OAEs and _____ (normal or abnormal) ABRs.

Josey (1987) reports the ABR has heightened test sensitivity to surgically confirmed lesions to 97%. The audiological test battery approach for acoustic neuromas is now often streamlined to pure-tone and speech audiometry, acoustic reflex assessment, OAEs, and ABR. A limitation of ABR testing presents itself in the presence of hearing poorer than 75 dB HL at 1000 to 4000 Hz (Josey, 1987). As discussed in Chapter 7, more recent use of the stacked ABR has resulted in the identification of smaller acoustic neuromas than previously identified through standard ABR measures. When the magnitude of hearing loss precludes

5. normal, abnormal

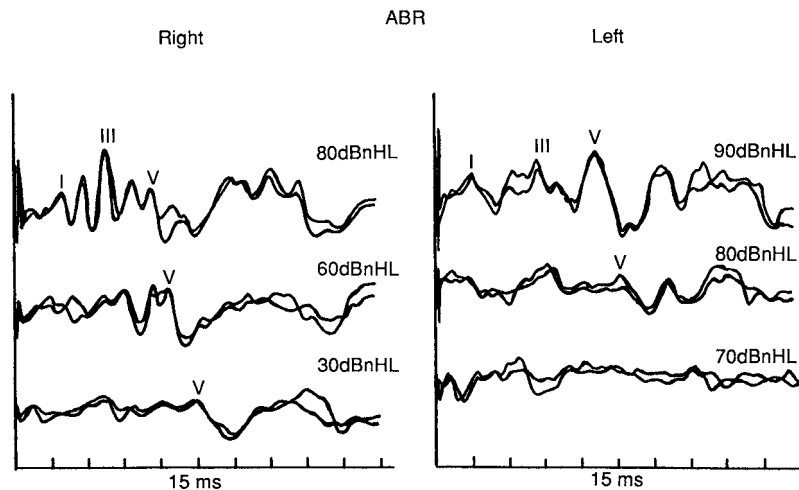


FIGURE 12.4 Results of auditory brainstem response testing on the patient with an VIIIth nerve hearing loss (acoustic neuroma) in the left ear (see Figure 12.2). See the latency-intensity functions for Wave V in Figure 12.5.

ABR testing, the physician's referral for diagnostic imaging may be based on audiometric and immittance results coupled with the patient's reported symptoms. The absence of OAEs in some cases may be the result of a concomitant, often unrelated, cochlear lesion and may confuse diagnosis.

Confirmation of acoustic neuroma is made through an interdisciplinary approach. Vestibular tests often show a number of abnormal signs, including spontaneous nystagmus with the eyes closed and generally decreased vestibular function on the affected side. An increase in the amount of protein in the cerebrospinal fluid is helpful in determining the presence of tumors. New advances in the specialty of medical imaging have vastly improved acoustic neuroma verification.

While it is important to consider the medical needs first for patients with acoustic neuroma, audiological regards should not be ignored. In post-operative patients and those electing to delay surgery, the hearing needs should be considered. Naturally, an ear with profound neural deafness will not respond favorably to a conventional hearing aid, but some patients with profound or total deafness in one ear have found that using a bone-anchored hearing aid (BAHA) can be of assistance (Syms, 2004). As discussed in Chapter 14, the aid is worn at the bad ear, and sound is conducted via bone conduction to the normal cochlea.

Other Causes of VIIIth Nerve Hearing Loss

Because of their dramatic symptoms and the danger they pose to the life of the patient, acoustic neuromas come to the audiologist's mind first when VIIIth nerve signs appear. This is a safe and prudent attitude, but other conditions of the auditory nerve can produce identical audiological symptoms. These conditions include **acoustic neuritis** (inflammation of the vestibular or cochlear nerve) and **multiple sclerosis (MS)**. A safe and prudent philosophy would be to assume that all unilateral sensory/neural hearings losses should be suspected of being acoustic tumors until proven otherwise.

6. True/False
Acoustic neuritis and multiple sclerosis may produce the same symptoms as acoustic neuroma.

SPEECH AND HEARING CENTER
The University of Texas at Austin 78712

NAME: Last - First - Middle	SEX	AGE	DATE	EXAMINER	RELIABILITY	INSTRUMENT

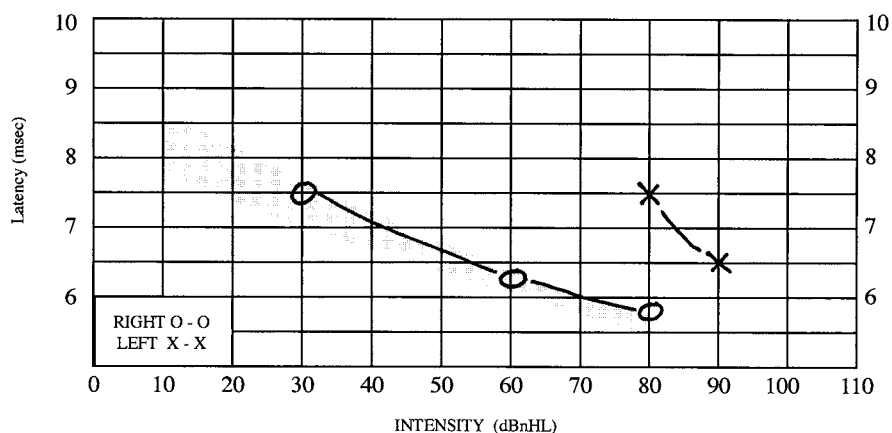
OTOACOUSTIC EMISSIONS
(Present or Absent)

☒ TEOAE Level **32** dB Peak SPL
☐ DPOAE Level F₁ ____ F₂ ____

Right					Left				
500	1000	2000	4000	6000	500	1000	2000	4000	6000
<i>P</i>	<i>P</i>	<i>P</i>	<i>P</i>	<i>P</i>	<i>P</i>	<i>P</i>	<i>P</i>	<i>P</i>	<i>P</i>

AUDITORY BRAINSTEM RESPONSE

ABR WAVE V LATENCY-INTENSITY FUNCTION



EAR	nHL		Absolute Latency (ms)			Interpeak Latency (ms)			Latency Change w/ Increased Rate	
	dB HL	Click Rate	I	III	V	I-III	III-V	I-V	V	Click Rate
RIGHT	80	13.1	1.9	3.8	5.8	1.9	2.0	3.9	6.0	89.1
LEFT	90	13.1	1.68	4.0	6.6	2.32	2.6	4.92	Absent	89.1
Interaural Differences										

Amplitude Ratio (V same or > I) R *NL* L *NL*
 Estimated Air Conduction Threshold R ____ L ____
 Estimated Bone Conduction Threshold R ____ L ____

FIGURE 12.5 Results of otoacoustic emissions testing showing the presence of these emissions in both ears at all frequencies. Latency-intensity functions for Wave V derived from the auditory brainstem response tracings shown in Figure 12.4, based on the patient with a unilateral retrocochlear hearing loss caused by an acoustic neuroma in the left ear (Figure 12.2). Wave V latencies are normal for the right ear and markedly increased for the left ear at all the sensation levels tested.

Auditory Neuropathy Spectrum Disorder (ANSD)

Auditory neuropathy spectrum disorder (ANSD) occurs when patients have normal outer hair cell function in the cochlea, but the responses on the VIIIth nerve that carries electrical signals to the brain fail to occur in synchrony; that is, they are dys-synchronous. The result is that instead of a smooth transition of information from the cochlea to the brainstem, the information is not relayed in a consistent manner. The degree of this dys-synchrony usually varies from individual to individual and often fluctuates in the same person (Hood, 2007).

Patients with ANSD often exhibit a mild-to-moderate sensory/neural hearing loss with speech-recognition difficulties disproportionate to the degree of the measured loss. These patients may also present with other peripheral neuropathies. In contrast, patients with acoustic neuroma exhibit preservation of ABR Wave I with an attenuation or delay of subsequent waves unless a profound loss exists that results in the absence of all waveforms. These patients' tumors will usually be evidenced on **magnetic resonance imaging (MRI)**. In comparison, patients with suspected ANSD may show an absence of all ABR waves when hearing thresholds may be only moderately impaired and there is no evidence of lesions of the VIIIth nerve or the brainstem on MRI. In addition, normal cochlear outer-hair-cell function is evidenced by the presence of evoked otoacoustic emissions (Starr, Picton, Sininger, Hood, & Berlin, 1996). The type of VIIIth nerve lesion present in these patients is not clear. Rapin and Gravel (2006) lament that ANSD is too frequently diagnosed solely based on audiological criteria rather than when behavioral, electrophysiologic, and pathologic testing indicate pathology of the spiral ganglion cells and their VIIIth nerve axons. The hearing loss seen in ANSD appears slowly progressive and does not demonstrate much benefit from hearing aids; however, other rehabilitative efforts including speechreading, **cued speech**, and cochlear implantation (see Chapter 14) may be helpful. Physiological tests in conjunction with behavioral audiometrics aid in the differential diagnosis of ANSD.

Medical Imaging. Remarkable technologies have been introduced to the science of medical imaging. The revolutionary development of **computed tomography (CT)** has permitted the viewing of numerous anatomical abnormalities in the body with sensitivity unrivaled by previous techniques. In this procedure, often called *computerized axial tomography (CAT)*, an X-ray transmitter scans in a transverse plane (at right angles to the long axis) of the head or body, along a 180-degree arc, while an electronic detector simultaneously measures the intensity of the beam emerging from the other side of the patient. With the aid of a computer, the detector's information is converted to a picture, or "slice," of the patient. This technology has permitted the noninvasive detection of intracranial hemorrhages, tumors, and deformities with great sensitivity.

Magnetic resonance imaging (MRI) has become an exciting adjunct to CT scanning. Using ionizing radiation to obtain images, MRI employs magnetic fields and radio waves to produce images in the different planes of the body. One of the most satisfying aspects of this technology is that the waves are believed to be virtually harmless. Furthermore, the technique is excellent for seeing many soft-tissue masses, such as acoustic neuromas, even when they are as small as just a few millimeters in diameter. An MRI scan of an acoustic neuroma is shown in Figure 12.6.

During head scans with both CT and MRI, the patient remains motionless while the head is scanned from within a large "doughnut" that surrounds it. Patients often find lying still on their backs difficult, and some who suffer from different degrees of claustrophobia become quite upset, even though the procedure is considered to be harmless. Often a chemical, such as gadolinium, is injected into the arm so that it can flow into the brain and serve as a contrast medium, allowing a mass to be seen more clearly. The noise emitted by many imagers is so loud that many radiologists provide foam hearing protectors for their patients.

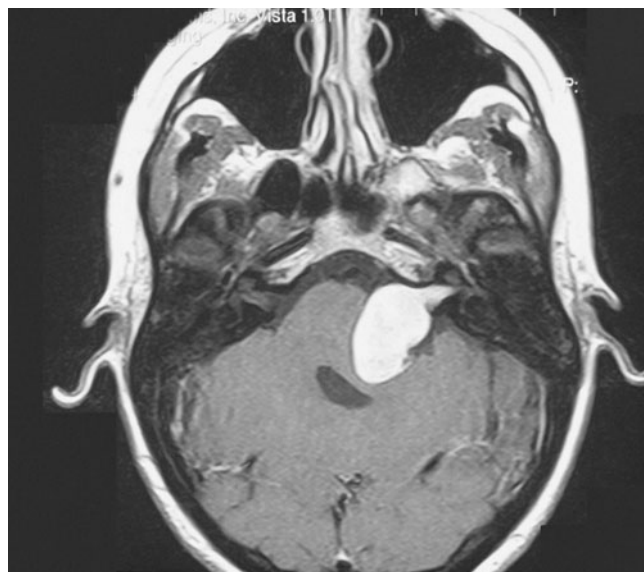


FIGURE 12.6 MRI scan showing a clinical orientation of a tumor in the left internal auditory canal. (Courtesy of Robert W. Keith, Ph.D.)

In a series of 100 patients with acoustic neuromas reported by Josey, Glasscock, and Musiek (1988), 93 had sufficient hearing to allow ABR testing, and 97% of that group showed abnormal ABR results reflecting the lesion. By contrast, 69% of the lesions were correctly identified by medical imaging alone. This result dramatizes the need to use both procedures in diagnosis.

Telian and Kileny (1988) reported three case histories in which ABR, ENG, CT, and MRI at times suggested different problems. In other words, some of the tests resulted in both false positive and false negative results. Telian and Kileny also concluded that false negative ABR responses are more likely to occur when an acoustic tumor is in the cerebellopontine angle than when it is in the internal auditory canal.

Abnormal ABR findings have been demonstrated in some cases of acoustic neuroma where no hearing loss exists. Despite this great sensitivity, the rate of false negative findings is, not surprisingly, slightly higher for ABR than for MRI, especially cases of very small tumors that produce only slight pressure on the auditory nerve. The fact that ABR is so much less expensive than MRI will ensure its continued use as a screening procedure for these tumors (Turner, Robinette, & Bauch, 1999).

Positron emission tomography (PET) is a procedure that utilizes radioactive materials emitted from the body after injection. This procedure is considered safe since the radioactivity levels decay very rapidly. PET is designed more to detect biochemical than anatomical changes in the patient, and it can be useful in the diagnosis of conditions like multiple sclerosis, Parkinson disease, stroke, schizophrenia, and even depression.

Disorders of the Cochlear Nuclei

The cochlear nuclei represent the first of the relay stations in the central auditory nervous system and the last point at which entirely ipsilateral representation is maintained. Because the tonotopic layout of these nuclei allows for frequency analysis, lesions in these areas may produce clinical loss of hearing sensitivity. Beyond the cochlear nuclei, a stimulus presented to one ear is processed and transmitted along fibers on both sides of the brain.

Audiologists work under the assumption that lesions central to the cochlea will produce results specific to retrocochlear disorders on special diagnostic tests. Such results are usually observed with VIIIth nerve lesions but are not always the case in the cochlear nuclei.

Causes of Cochlear Nuclei Disorders

Damage to the cochlear nuclei is difficult to diagnose with certainty without postmortem study. Lesions in the nuclei, like those on the auditory nerve, may result from disease, toxicity, irritation, pressure, or trauma.

Rh incompatibility was discussed briefly in Chapter 10 as a prenatal cause of cochlear hearing loss. Postmortem studies have shown deposits of bilirubin in the cochlea, as well as in different areas of the brain, including the cochlear nuclei. Goodhill (1950) coined the term *nuclear deafness* to describe the site of lesion in children with hearing loss who have cerebral palsy secondary to Rh incompatibility.

The term **kernicterus** has been used for some time to describe the condition characterized by bile deposits in the central nervous system. Kernicterus often results in degeneration of the nerve cells that come into contact with liver bile.

Conditions that interfere with or alter the blood supply to the cochlear nuclei may result in hearing loss. Such disorders, called *vascular accidents*, include the rupturing of blood vessels as well as clots that obstruct the arterial space. These clots may be either *thromboses*, which form and remain in a specific area of the vessel, or *embolisms*, which are formed by bits of debris that circulate through the system until they reach a narrow passageway through which they cannot pass. Either one may obstruct the blood vessel or cause it to burst. Arteries have also been known to rupture where aneurysms (dilations in the blood vessels) form, because aneurysms usually cause the walls to become stretched and thin. Cases of obstruction or rupture of blood vessels within the brain are called **cerebrovascular accidents (CVAs)** or *strokes*.

An increasingly common condition today is arteriosclerosis, or hardening of the arteries. In addition, the narrowing of the lumen within an artery may be associated with accumulations of fatty debris due to improper diet, insufficient exercise, or metabolic problems. When blood supply to critical nerve cells is diminished, the result is **anoxia**, which alters cell metabolism and may cause destruction of nerve tissue.

7. Cerebrovascular accident (CVA) is also called _____.

A number of congenital defects of the brain including the central auditory pathways have been described in the literature. These defects may be the result of birth trauma or agenesis of parts of the brain.

Pressure within the brainstem may also produce hearing loss. This pressure may be caused by tumors (either benign or malignant), by increased cerebrospinal fluid pressure produced secondary to trauma, or by direct insult to the head. Hemorrhage produced by vascular or other accidents may also cause pressure and damage.

Syphilis (lues) can produce damage anywhere in the auditory system, from the outer ear to the cortex. Cells are damaged or destroyed either by direct degeneration of the nerve units or, secondarily, by CVAs associated with the infection.

Degeneration of nerve fibers in the brain is expected with advancing age. Although presbycusis was listed as one of the causes of cochlear hearing loss, it has become accepted that, with aging, changes occur virtually everywhere in the auditory system, including the brainstem. Diseases such as multiple sclerosis can produce degeneration of nerve fibers in younger people as well.

8. Oxygen deprivation is called _____.

Disorders of the Higher Auditory Pathways

The types of disorders that affect the cochlear nuclei may also affect higher neural structures. Tumors, for example, are not limited to specific sites. Head injury, the major cause of death or serious brain damage among young people in the United States, can produce lesions in a variety of sites. Lesions may encompass large portions of the brain or be localized to small areas.

Factors influencing audiometric results include not only the sizes of the lesions but also their locations. Lesions of the temporal cortex, such as from CVA or epilepsy, usually lead to abnormal results on special tests in the ear contralateral to the lesion. Lesions in the brainstem are not so predictable.

Jerger and Jerger (1975) point out that when a lesion is **extra-axial** (on the outside of the brainstem), audiometric symptoms appear on the same side of the head. Such patients often show considerable loss of sensitivity for pure tones, especially in the high frequencies. When the lesion is **intra-axial** (within the brainstem), central auditory tests may show either contralateral or bilateral effects. Often, hearing sensitivity for pure tones is normal or near normal at all frequencies.

Auditory Processing Disorders

The principal function of the central auditory system is to organize concurrent or sequential auditory input into definite patterns. The subsequent ability to comprehend and develop spoken language is primarily dependent upon the success of the entire auditory system to process speech signals. In an attempt to avoid implicating an individual anatomical site by recognizing the

interplay between peripheral and central pathologies, participants of a consensus conference recommended the clinical entity previously referred to as **central auditory processing disorder (CAPD)** be more operationally defined as **auditory processing disorder (APD)** (Jerger & Musiek, 2000). Although the conference addressed APD in children, it seems logical to extend this operationally inclined definition to auditory processing disorders of

adults as well. Many with APD have difficulty in the interpretation of auditory information in the absence of a concomitant loss of peripheral hearing sensitivity. These processing difficulties are further compounded in the presence of surrounding auditory, or sometimes even visual, distractions. Discussion of the management of auditory processing disorders is presented in Chapter 15.

On occasion, patients present with complaints of decreased hearing abilities, although subsequent routine hearing tests reveal normal peripheral hearing. These patients may be distressed over their difficulties in auditory functioning within social contexts and concerned with potential deterioration in their hearing. In the absence of identifiable peripheral pathology or disconcerting unilateral symptoms, most of these patients are discharged with simple reassurance, leaving unanswered questions regarding the underlying problem. Patients following this scenario have been classified as having **obscure auditory dysfunction (OAD)** (Saunders & Haggard, 1989, 1993). It is probable that given testing directed specifically at auditory processing, many of these patients would be found to have an auditory processing disorder, resulting in the elimination of the obscurity of the diagnosis.

APDs occurring later in life, secondary to disorders such as CVAs, head trauma, brain tumor, or multiple sclerosis, have less chance of recovery than do APDs in the pediatric population. Because of the adaptive properties of the younger central nervous system, children have the advantage of compensatory development of other areas within the system. Auditory processing

9. True/False
Individuals with APD
often have normal
hearing sensitivity.

deficiencies may result in lack of attention to auditory stimuli. This increases distractibility, decreases auditory discrimination and localization abilities, and makes comprehension of speech more difficult. Difficulty with auditory figure-ground differentiation results in a decreased ability for selective attention. One cause for these deficiencies in children appears to be the decrease and fluctuation in the intensity of auditory input secondary to recurrent otitis media.

Minimal Auditory Deficiency Syndrome

The animal brain is characterized by an extremely well-organized system of representation for response to incoming signals. When there is deprivation of sensory input, such as to visual or auditory signals, marked changes may take place in the brain (Schwaber, 1992). The tendency of cells to become altered in order to conform to their environments is called **plasticity**. Changes in structures in the brain may take place as a result of the sensory deprivation caused by either cochlear or conductive hearing losses.

The slight or mild hearing loss that is often associated with otitis media may go undetected in very young children. Even when it is correctly diagnosed, parents and physicians alike are relieved when symptoms abate and the child appears normal in all respects. Experts have recognized that even these transient and very mild conductive hearing losses may affect the development of skills essential to the learning of language. The term ascribed to this set of circumstances is the **minimal auditory deficiency syndrome (MADS)**.

10. True/False
MADS may be caused by even very mild conductive hearing losses.

What may be happening in the young human brain has been demonstrated in the laboratory on experimental animals (e.g., Webster & Webster, 1977). Within 45 days, mice with conductive hearing loss surgically induced shortly after birth showed smaller neurons in the cochlear nuclei, superior olivary complex, and trapezoid body than did mice in the control group. Katz (1978) reported that the attenuation of sound may produce similar effects in children and contribute to the development of learning disabilities.

Concern over the relationship between language disorders and otitis media was demonstrated by Rentschler and Rupp (1984). These researchers found that 70% of a group of speech- and language-impaired children also had histories of hearing problems, and they suggested persistent monitoring of children with middle-ear disorders through tympanometric measures.

Although the population they studied was small, Gunnarson and Finitzo (1991) looked at a group of children with conductive hearing loss and the later effects on the electrophysiology of the brainstem. They concluded that there do appear to be effects of early transient hearing loss on auditory brainstem responses and that adequate sensory input to the central auditory nervous system is important to the brain during critical developmental periods.

The American Academy of Audiology (2000) issued a position paper on the guidelines for diagnosing and treating otitis media in children. Although some controversy continues to exist, many are now convinced of a cause-and-effect relationship between early and recurrent otitis media and later learning and communication disorders. It is not the extent of the hearing loss that is the precipitating factor, but rather the fluctuating nature of the disorder and the fact that differences in hearing sensitivity between the two ears of a child may result in abnormal development of auditory processing skills, which are dependent on binaural interactions in the brain. There is no disagreement that the primary responsibility for treating otitis media lies within the medical domain; however, the diagnosis and management of subsequent hearing loss is the responsibility of the audiologist.

The American Academy of Audiology (2000) recommends the following:

1. *Identification.* This includes screening at-risk children such as those who develop otitis media at or before the age of six months, those who attend daycare centers, those with cleft lip or palate or Down syndrome, and Native Americans. Screening should include the functions of the middle ear, hearing, and language development. Children who fail the screening should be referred for in-depth testing and possible remediation. Those failing communication screenings may need referral for further evaluation and communication therapy from a speech-language pathologist.
2. *Assessment.* Air- and bone-conduction audiometry for both ears should be carried out to determine the degree of hearing loss and the audiometric configuration. Speech audiometry, along with acoustic immittance tests and a battery of tests for auditory processing disorders, should be administered when practicable. Referral to speech-language pathologists should be made on the basis of the outcome of these tests.
3. *Audiometric Monitoring.* Periodic audiometric follow-up should be completed, even when the child is asymptomatic. Hearing tests should be carried out at the beginning of every school year and at least once during the winter. Parents or caregivers should be kept apprised of hearing test results, and their concerns over their children's hearing status should be carefully heeded. Parents or caregivers and teachers should also be taught skills for dealing with their children during exacerbations of hearing loss, ways of recognizing the possible development of hearing loss, and systems for minimizing the disruption of classroom learning by attention to the learning environments of at-risk children.

Although it is recognized that not all children who suffer repeated bouts of otitis media will develop conditions that cause them to fall short of their genetic potential for learning, prudence demands that all persons who interact with these children should be alerted to the potential dangers.

Central Deafness

Cases of central deafness are extremely rare, occurring when both hemispheres of the brain are severely compromised. Although responses to behavioral audiometric tests may be absent, these patients typically have normal acoustic reflexes and ABRs. Such findings are usually secondary to vascular lesions of the middle cerebral artery or its branches.

Tests for Auditory Processing Disorders

Lesions in the auditory nerve and cochlear nuclei produce obvious and dramatic hearing symptoms in the ear ipsilateral to the lesion. As stated earlier in this chapter, once the level of the olivary complex is reached, both sides of the brain are involved in the transmission of auditory information. Even large lesions in the brain may produce either no audiological symptoms or symptoms that are very subtle. For this reason, emphasis must be placed on developing tests that are specifically sensitive to lesions in the central auditory system, many of which are reviewed in this chapter.

For the most part, tests using pure tones have been unsuccessful in identifying central auditory lesions. Because pure-tone tests have been disappointing, much of the past and current emphasis in diagnosing auditory processing disorders has been placed on speech tests, many of which are available commercially.³ As Keith (1981) points out, tests to evaluate these disorders in children share certain characteristics, including language-dependent administration and

scoring. Clearly tests that rely on speech stimuli must be used with caution if the patient exhibits speech-recognition difficulties. Given this caveat, one can expect more nonverbal tests for auditory processing disorder in the future.

11. True/False
Hearing loss on pure-tone tests is a common alert to APD.

Gaps-in-Noise Test

The Gaps-in-Noise (GIN) test (Musiek et al., 2005) represents a measure to assess temporal-processing abilities with a nonverbal task. During this test, the individual is to identify the presence of gaps between 2 and 20 ms in duration within a 6-second broad band noise signal. The effect of any existing frequency-specific hearing loss is minimized through the use of a broadband test signal, and the relatively simple nature of the task limits the effects of patient language and cognitive skills. The test can be performed with any clinical audiometer connected to a CD player. Another commercially available temporal-processing test, the Random Gap Detection Test (RGDT) similarly limits the effects of patient language skills and has established normative data for children, adults and older adults (Keith, 2000).

Masking-Level Difference

The phenomenon of binaural release from masking, or **masking-level difference (MLD)**, has been known for some time (Hirsh, 1948). To determine the MLD, the binaural threshold is determined for a low-frequency tone presented in phase to the two ears in the presence of a binaural noise, also in phase. When the threshold is remeasured with the tones 180 degrees out of phase with the noise, a threshold improvement is found on the order of 10 to 15 dB. Abnormal MLDs in normal-hearing subjects strongly suggest a brainstem lesion (Noffsinger, Martinez, & Schaefer, 1985), but positive findings have also been observed in cases of acoustic neuroma, presbycusis, Ménière's disease, and particularly multiple sclerosis (Mueller, 1987a). MLDs have also been measured using speech signals.

Although the effects of cochlear and cortical lesions on MLD are somewhat unpredictable, there is general agreement among researchers (e.g., Olsen & Noffsinger, 1976) that the release from masking is either absent or significantly less than normal in patients with lesions in the brainstem. If the clinician has access to a device capable of shifting the phase of the pure tone without affecting the phase of the noise, simply measuring several binaural pure-tone thresholds may provide additional insight into site of lesion.

While the advantages of including MLD testing in the assessment of auditory processing disorders have been documented for some time, including the fact that this test represents another non-language-based assessment, the lack of practical administration of this assessment tool has frequently relegated it to the realm of research investigations. A simplified protocol for the administration of MLD testing using a standard CD player (Wilson, Moncrieff, Townsend, & Pillion, 2003) holds promise for increasing clinical use of this measure of auditory perceptual abilities. Unlike the Gaps-in-Noise test, approaches to measuring MLD through any approach may be complicated by any degree of peripheral hearing loss.

The Dichotic Digits Test

Musiek (1983) describes a version of the **dichotic digits test** as being useful for diagnosing both brainstem and cortical disorders, although it may not be possible to tell one lesion site from the other on the basis of this test alone. Twenty sets of two-digit pairs are presented at

50 or 60 dB above the SRT. The digit 7 is omitted because it is the only one that has two syllables. The patient hears two successive pairs of two digits and is asked to repeat all four digits. The test can also be done with three-digit pairs but may result in low scores for some individuals because of short-term memory difficulties. For this reason, Mueller (1987a) believes that the two-digit pair test is probably better for detection of lesions in the central auditory nervous system.

Performance-Intensity Function Testing

Jerger and Jerger (1971) described the use of the **performance-intensity function for PB words (PI-PB)** as a method of screening for central auditory disorders. As discussed in Chapter 5, whether word-recognition test lists are truly phonetically balanced is unlikely and research suggests that attempts at such balancing may not even be necessary (Martin, Champlin, & Perez, 2000). In addition to testing with words, performance-intensity functions have been assessed with sentence-length speech-recognition tests as well. Patients with normal hearing sensitivity who show differences in the scores and shapes of the PI curves may be suspected of central disorders. Speech-recognition tests are presented to the patient at a number of levels—for example, 60, 70, 80, and 90 dB HL. The tests are scored, and a graph may be drawn for each ear, showing the speech-recognition scores as a function of presentation level.

If a significant difference in scores occurs between ears (20 to 30 percent), it may be suspected that a central lesion is present on the side of the brain opposite the poorer score. Sometimes “rollover” of the curve occurs; that is, at some point scores begin to decrease as intensity increases (Figure 12.7). Rollover suggests a lesion on the side of the brain opposite the ear with the rollover or a lesion of the VIIIth nerve on the same side (Figure 12.2). PI functions may not be helpful in detecting central lesions if a loss of hearing sensitivity is also present.

A rollover ratio is derived by the following formula:

12. In acoustic neuroma it is expected that there will be a high rollover ratio in the _____ (same/opposite) ear.

$$\text{Rollover ratio (\%)} = \frac{\text{Max} - \text{Min}}{\text{Max}}$$

“Max” is the highest score and “Min” the lowest score obtained at an intensity above that required for the “Max” (Jerger & Jerger, 1971). Rollover ratios of .40 suggest cochlear lesions, whereas ratios of .45 or greater indicate an VIIIth nerve site. High rollover ratios are also seen in some elderly patients (Gang, 1976), probably reflecting some degree of central presbycusis.

Two factors must be considered when determining rollover ratios. First, the procedure is not helpful if all speech-recognition scores are low. Second, for the greatest accuracy, a number of levels must be tested. Establishing complete performance-intensity functions can be very time-consuming. However, when a central pathology is suspected, a comparison of performance of a high intensity speech-recognition measure (90 dB HL, tolerance permitting) with that of an estimate of maximum performance (closely estimated by testing at 5 to 10 dB above the most-comfortable level) may be revealing. A decrease of 20% or more at the higher level can be considered an indication of central involvement. As this is a measure significantly above threshold, masking of the contralateral ear must usually be employed.

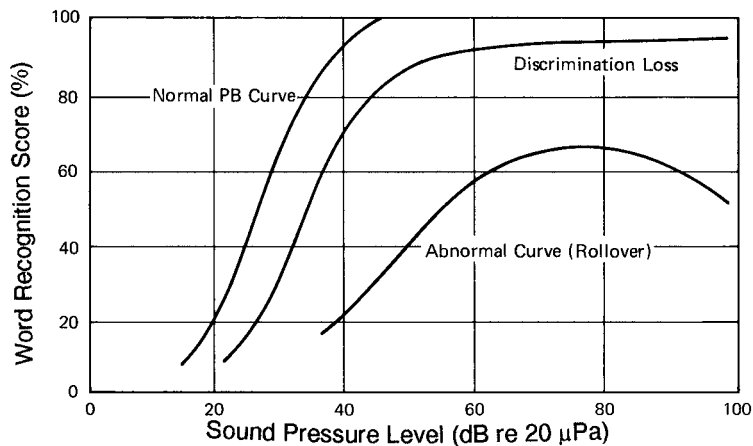


FIGURE 12.7 Typical performance-intensity functions for words showing the normal increase in word-recognition scores with increased intensity and the rollover (decreased discrimination beyond a certain level) evident in some ears contralateral to a central auditory disorder.

Listening in Spatialized Noise Test

Capitalizing on the central auditory system's need to adequately utilize binaural cues to differentiate the location of competing signals from the message that one is listening to, the Listening in Spatialized Noise test (Cameron, Dillon, & Newall, 2006) creates a virtual (under earphones) three-dimensional listening environment to detect auditory figure-ground discrimination deficits. This test, which can be administered with standard audiometric equipment and a personal computer, may have a higher specificity in identifying children with problems in binaural processing. It uses special distribution of sound sources for suppression of auditory distractions: a common difficulty reported for children suspected of having auditory processing difficulty.

Filtered Speech Tests

Although standard tests for speech recognition do not usually identify central lesions, it has been known for many years that distortion of the speech signal presented monaurally often results in reduced speech-recognition scores in the ear contralateral to a central lesion (Bocca & Calero, 1963; Goetzinger & Angell, 1965). This statement is true if the lesion does not impair the symbolization and memorization processes of the brain, which may result in much more demonstrable symptoms. Subsequent studies of distorted speech testing with suspected central lesions has used speech signals that have been periodically interrupted, masked, compressed in time, presented at low sensation levels, and filtered. Filtering some frequencies from the speech spectrum has become the most popular of these methods. These test methods often follow Bocca's (1967) early suggestion that distorted sentence materials are superior to isolated words because they put greater stress on the brain's capacity for pattern recognition.

A speech signal may be passed through a filter that rejects the low frequencies and passes the highs (high-pass filter) or one that rejects the high frequencies and passes the lows (low-pass filter). A signal may also be processed through a filter that rejects both high and low frequencies above and below a prescribed range, so that only a band of frequencies is allowed through. This is called band-pass filtering and is usually described in terms of the range from the lowest to the highest frequencies passed.

Difficulty in recognizing filtered speech depends largely on the filter characteristics, such as whether the signal is high-pass, low-pass, or band-pass filtered; the cutoff frequency of the filter (the precise frequency above or below which the filtering takes place); and the filter rejection rate (usually expressed in decibels per octave). The steeper the rejection rate, the greater the distortion of the signal. Filtered speech tests may be performed monaurally or binaurally.

Filtered speech tests presented monaurally have been found to yield scores markedly poorer in patients with brainstem lesions and in the ear contralateral to temporal lobe lesions (Antonelli & Calero, 1968; Bocca, Calero, & Cassinari, 1954; Hodgson, 1967; Jerger, 1960; Lynn & Gilroy, 1977).

Filtered speech tests may also be carried out binaurally as first demonstrated by Bocca (1955), who found that combining a quiet undistorted signal to one ear with the same signal to the other ear, at a high level but distorted, yields surprising results when the central auditory pathways are intact. Discrimination for soft speech is naturally poor, as is discrimination for loud, distorted speech. When the two signals are presented simultaneously (soft to one ear, distorted to the other), a dramatic increase in the speech recognition score is observed as the two signals are fused in the brain. No such summation of scores was observed by Jerger (1960) or Calero (1957) in patients with temporal lobe disorders.

Band-Pass Binaural Speech Audiometry

Matzker (1959) was first to develop a test wherein different filtered portions of a speech signal are presented to each ear. Discrimination for either a low-frequency band-passed signal alone or a high-frequency band-passed signal alone yields very poor speech intelligibility. If the brainstem is normal, the two signals are fused when presented simultaneously. Inability to demonstrate this binaural fusion suggests a lesion in the brainstem.

One method for this test has been described by Smith and Resnick (1972). The low-frequency band of words is presented at 30 dB SL through one channel of a two-channel speech audiometer. The high-frequency band, controlled by the hearing-level dial of the second channel, is presented 10 dB above the level set for the low band. Three test conditions exist:

1. Low band to the right ear, high band to the left ear (**dichotic**)
2. Low band to the left ear, high band to the right ear (dichotic)
3. Both bands to both ears (**diotic**)

The Smith and Resnick (1972) procedure with CNC words, which they call dichotic binaural fusion, has gained some clinical prominence. There appear to be no differences in the three scores in patients with normal hearing, cochlear lesions, or lesions of the temporal lobe. Patients with brainstem disorders show significant diotic-score enhancement over one or both of the dichotic scores.

In a similar test, Palva and Jokinen (1975) found that patients with disorders of the auditory cortex show poor scores when both bands are presented to the ear contralateral to the lesion, although their dichotic scores are good. Patients with brainstem lesions show especially poor scores for binaural fusion.

Martin and Clark (1977) employed a comparison of diotic and dichotic presentations of the WIPI test to young children so that a picture-pointing procedure could be used as a screening test for children with auditory-processing disorders. They found that diotic presentation improved discrimination scores by 10% and that a control group did about as well on the more difficult dichotic task as on the diotic one. As with any screening test for children who show normal hearing on standard audiometric procedures but whose histories suggest the possibility of central deficits, those who fail the test should be referred for in-depth testing of auditory processing abilities (see Table 12.1).

TABLE 12.1 Band-Pass Filter Settings Used in Five Studies of Binaural Fusion

	<i>Low-Frequency Band (Hertz)</i>	<i>High-Frequency Band (Hertz)</i>
Matzker (1959)	500–800	1815–2500
Hayashi, Ohta, & Morimoto (1966)	300–600	1200–2400
Franklin (1966)	240–480	1020–2040
Smith & Resnick (1972)	360–890	1750–2200
Palva & Jokinen (1975)	420–720	1800–2400

Synthetic Sentence Identification Tests

The synthetic sentence identification (SSI) test, described in Chapter 5, may be used to identify lesions of the central auditory system. The sentences are made more difficult to identify by using a competing message, a recording of continuous discourse. This may be an *ipsilateral competing message (ICM)*, which is presented to the test ear along with the synthetic sentences, or it may be a *contralateral competing message (CCM)*, which is presented to the opposite ear. With the test materials (SSI) fixed at a given sensation level, the competing message may be varied in intensity so that a number of message-to-competition ratios (MCRs) are obtained (Jerger, 1973).

According to Jerger (1973), normal-hearing persons will perform at the 100% level on the SSI-ICM test with an MCR of 0 dB, 80% with an MCR of –10 dB, 55% with an MCR of –20 dB, and 20% with an MCR of –30 dB (competing message 30 dB above the sentences). Patients with lesions of the brainstem show large differences in scores between the right and left ears on this test. With an increase in the level of the competing message, scores deteriorate more rapidly than normal when the test is performed in the ear contralateral to the lesion. For example, for a patient with a lesion of the left brainstem, SSI-ICM scores will be poorer in the right ear than in the left ear.

The SSI-CCM test is performed in precisely the same manner as the SSI-ICM, the only difference being that the competing message is presented to one ear and the sentences are presented to the opposite ear. The MCR is varied up to –40 dB.

Persons with normal hearing and normal central auditory function will perform very well on the SSI-CCM test, even at MCRs of –40 dB. The competition of the other ear seems to have little effect on the ability to understand the synthetic sentences. Patients with lesions of the temporal lobe perform well when the sentences are presented to the ear on the same side as the lesion while the competing message is presented to the other ear. When the sentences are presented to the ear on the unimpaired side and the competition is presented to the ear on the same side as the cortical lesion, deterioration of scores ensues. For example, in a left cortical lesion, SSI scores will be good with sentences in the left ear and competition in the right ear, but scores will be poor with sentences in the right ear and competition in the left ear. Jerger (1973) therefore believes that the use of ipsilateral and contralateral competing messages with the SSI not only reveals central disorders but actually separates lesions of the brainstem from those in the cortex.

13. SSI-ICM is expected to reveal lesions in the _____ while SSI-CCM should indicate lesions in the _____.

Competing Sentence Tests. Building on work begun a decade earlier, Williford (1977) reported on the use of natural sentences in diagnosing central auditory disorders. The Competing Sentence Test (CST) is made up of natural sentences and, unlike the SSI procedure, uses an

open-message set. To make the procedure useful, of course, a competing message is presented to the opposite ear.

The primary message is presented at a level 35 dB above the pure-tone average (PTA) while the competing message is presented at 50 dB above the PTA. Both sentences are the same length and on the same subject (e.g., time, food, weather, family). Fifteen sentences are used. The patient is told to repeat only the primary (softer) sentence. Because many brain-injured patients have difficulty in attending to soft stimuli or those under conditions of adverse message-to-competition ratios, modifications of the original method have been developed (Bergman, Hirsch, Solzi, & Mankowitz, 1987).



Examples of the CST are included in the word list section under “Forms” in the Professional Resources section of the Companion Website.

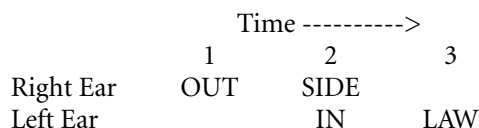
Patients with lesions of the temporal lobe show the greatest difficulty when the primary sentence is presented to the ear contralateral to the lesion. Simple versions of the procedure have been used successfully to identify children with learning disabilities. Children tend to improve on this test as they get older, which is not surprising because the central auditory nervous system probably continues to mature until about 9 years of age.

Rapidly Alternating Speech Perception (RASP)

A test has been designed that rapidly alternates six- or seven-word sentences between the ears (Williford, 1977). The 20 sentences, presented at 50 dB above the SRT, are switched back and forth every 300 milliseconds. For the patient to understand and repeat the sentences, brainstem function must be normal, because any segment presented to one ear alone is presumably too short to allow discrimination. The procedure is called the **Rapidly Alternating Speech Perception (RASP) test**.

The Staggered Spondaic Word (SSW) Test

Katz (1962, 1968) developed a test of dichotic listening that has undergone more standardization on English-speaking adults than most of the other tests for central auditory disorders and has been shown to differentiate between normal children and those with learning disabilities (Berrick et al., 1984). The **Staggered Spondaic Word (SSW) test** is a measure of dichotic listening that utilizes spondee words in a suprathreshold manner. Pairs of different spondaic words are presented to each ear, with some timing overlap for both ears. The first syllable of one spondee is presented to one ear, and while the second syllable is presented, the first syllable of the other spondee is presented to the other ear. Then the second syllable of the second spondee is presented alone. This procedure is diagrammed as shown:



Naturally, the very nature of this test precludes the use of masking, but insert receivers are useful in increasing the interaural attenuation. Poor scores on the SSW test suggest a lesion in the higher brain centers on the side contralateral to the low-scoring ear. Although the SSW

test is very popular, one lasting complaint concerns the amount of time needed to follow the complex scoring system. At least one computer program is now available for this purpose. Mueller (1987b) has suggested that diagnosis with the SSW test may be carried out simply by computing the score for each ear on the basis of the percentage of words identified correctly.

Time-Compressed Speech

With special recording devices it is possible to speed up the playback of speech stimuli without significantly creating the perception of higher vocal pitch. This **time-compressed speech** has been studied by using the words from the NU-6 lists. Central auditory lesions are best identified at 60% time compression (Kurdziel, Noffsinger, & Olsen, 1976). Kurdziel and colleagues found that, in some brain lesions, time-compressed word-recognition scores were poor in the ear contralateral to the lesion, whereas in other cases scores remained normal in both ears. There has not been much information in the recent literature on the use of time-compressed speech in cases of central auditory nervous system damage.

Screening Test for Auditory Processing Disorders

The **Screening Test for Auditory Processing Disorders (SCAN)**⁴ was devised as a rapid procedure to detect auditory processing difficulties in children aged 3 to 11, so that their risk factors may be determined and specific management strategies applied. Its standardization (Keith, 1986) appears to be more extensive than some of the other tests for central auditory disorders. The SCAN comprises three subtests: The filtered-word subtest contains two lists of 20 monosyllabic words that are low-pass filtered at 1000 Hz (with a rejection rate of 32 dB per octave) and are presented by audiotape or CD to one ear at a time. The auditory figure-ground subtest likewise contains two monosyllabic 20-word lists, presented to each ear in the presence of a background noise made up of a multitalker babble. A signal-to-noise ratio of +8 dB is used. The competing-word subtest comprises two lists of 25 monosyllabic words presented dichotically (one word introduced to each ear simultaneously). The child is instructed to repeat the word heard in the right ear followed by the word heard in the left ear. Comparisons to other tests for central auditory disorders suggest that the SCAN may be a useful procedure (Keith, Rudy, Donahue, & Katfamma, 1989).

In response to a need for well-standardized central auditory tests for persons over 11 years of age, Keith (1994, 1995) modified the SCAN for use with older subjects. The SCAN-A is an upward extension of the SCAN designed for use with adolescents and adults with neurological disorders and learning disabilities. A caution was raised by Woods, Pena, and Martin (2004) about the possible contamination of results on the SCAN based on ethnic differences so these should be considered carefully in interpretation.

Acoustic Reflex Test

Comparison of ipsilateral and contralateral acoustic reflexes can be of great value in determining the integrity of the crossover pathways in the trapezoid body of the brainstem. If, for example, a patient has normal hearing and normal ipsilateral acoustic reflexes in both ears, it is highly probable that the cochleas, the VIIth and VIIIth cranial nerves, and the middle-ear mechanisms are intact on both sides. If, in the same individual, the contralateral reflexes are absent, the most likely explanation is that damage exists within those crossover pathways (see Table 7.2I and J).

Auditory Evoked Potentials

Auditory brainstem response audiometry has been useful in diagnosing central auditory disorders as long as any hearing loss in the two ears is essentially symmetrical and no more than a mild loss exists in either ear (Musiek, 1983). The presence of concomitant peripheral lesions may confound interpretation of ABR results if lesions are present in both the cochlea and the brainstem. Central lesions will generally slow the conduction velocity of electrical impulses sent through the nerve fibers. Musiek suggests the following general observations:

Wave I (all waves) delay	Lesion in outer, middle, or inner ear
Wave I–III delay	Lesion in auditory nerve or lower brainstem
Wave III–V delay	Lesion in higher brainstem

In testing for lesions of the brainstem, it is useful to compare the latencies and intervals of Waves I, III, and V as a function of increased click rates. Although the ABR results may provide important diagnostic information in testing for central auditory lesions, interpretation can be difficult when it is complicated by the absence of some waves, the influence of unusual audiometric configurations, and the patient’s age and body temperature. The ABR is generally the most sensitive and specific test currently available for diagnosis of auditory brainstem lesions, although the use of the complete central test battery remains important (Chermak & Musiek, 1997).

The P300, or cognitive potential of the late auditory evoked response, is elicited by an “oddball” paradigm, whereby the subject tries to discriminate between a frequently occurring stimulus and a rarely occurring stimulus. For example, a 1000 Hz tone burst is presented 80% of the time, and a 2000 Hz tone burst is presented randomly 20% of the time. The subject is asked to count only the higher-pitched tones. The waveform elicited by the rare (2000 Hz) stimulus shows a large positive peak with a latency of approximately 300 milliseconds. Reduction in amplitude, or increase in the latencies of the P300, has been found in elderly individuals, those suffering from dementia, and head trauma patients. This procedure is thought to hold future promise as a diagnostic procedure for other disorders of the central auditory nervous system. Indeed, Hall (2007) reports an abnormal P300 response in a large number of children being assessed for auditory processing disorder.

Otoacoustic Emissions

It has been emphasized in this book that otoacoustic emissions (OAE) have come into their own as a powerful clinical tool with a variety of applications (see Chapter 7). For example, Jerger, Ali, Fong, and Tseng (1992) reported on a patient with multiple sclerosis in whom it was possible to identify the source of the speech-recognition difficulty she experienced in one ear as retrocochlear. The presence of distortion product OAEs in this case suggested that at least the outer hair cells of the cochlea were functioning normally. The diagnosis of a more central lesion was confirmed by MRI of the brain. Cevette, Robinette, Carter, and Knops (1995) also reported on the important contribution OAEs can make to the diagnosis of multiple sclerosis.

Although the role of OAEs in the diagnosis of acoustic neuroma is limited, OAEs have been used in intraoperative monitoring and as a preoperative and postoperative measure of cochlear function. In the operating room, distortion-product OAEs have been demonstrated to reveal earlier evidence of cochlear compromise than monitoring with ABR (Telischi, Widick, Lonsbury-Martin, & McCoy, 1995).

14. OAEs are expected to be _____ in central auditory lesions.

Cases of auditory neuropathy/auditory dys-synchrony are relatively uncommon. However, it is the ability of OAEs to objectively assess cochlear function that helped to identify this clinical entity when absent ABRs were seen in the presence of only mild to moderate hearing loss. It may be anticipated that further reports of the increasing clinical utility of OAEs will be forthcoming.

Approaching APD through a Battery of Tests

While administration of electrophysiological tests is more costly than that of behavioral measures, behavioral tests are not always feasible as with patients with aphasia or central deafness. The sensitivity of testing for lesions of the auditory nerve and central auditory pathways increases when behavioral and electrophysiological measures are combined. In addition, the audiologist's confidence in making a diagnosis of auditory processing disorder is heightened when abnormalities are found in both the behavioral and electrophysiological domains (Chermak & Musiek, 1997).

The Bruton Conference on auditory processing disorders recommended a battery of tests including behavioral and electroacoustical/electrophysiological measures (Jerger & Musiek, 2000). On the behavioral side, participants advocated a combination of pure-tone audiometry to assess for peripheral hearing loss, performance intensity function testing to compare performance between the ears, dichotic tasks, and measures of auditory temporal processing. Recommended electroacoustic/electrophysiologic measures included immittance measures to rule out middle-ear disorder and to identify acoustic reflex abnormalities, OAEs to rule out inner-ear disorders, and ABR and middle latency response as measures of auditory structures at brainstem and cortical levels. The diagnosis of APD is best carried out through a team approach, capitalizing on the backgrounds of audiologists, speech-language pathologists, and educational psychologists.

Clinical Commentary

The aim of behavioral measures of central function has changed over the years. While these tests were originally designed to help identify the site of lesion of neuropathology, this role has largely been supplanted by the more objective electrophysiological and electroacoustical measures and the advances in medical imaging. Today, behavioral measures of central auditory function are more frequently employed as screening measures for potential disorders rather than as diagnostic indices. Their true value to the audiologist has evolved in their ability to describe the communication impact of auditory processing disorders. It is based upon the study of communication impact that therapeutic intervention can better be designed and implemented. For discussion of management of auditory processing disorders see Chapter 15.

Summary

This chapter has dealt with the function and audiological diagnosis of lesions of the auditory nerve and central auditory nervous system. Although considerable mystery continues to surround the central nervous system, nowhere is this mystery greater than in the higher auditory pathways. Impulses that pass from the cochlea are transmitted by the auditory nerve to the cochlear nuclei, which are waystations for transmission to higher centers and areas for complex frequency and temporal analysis. The cochlear nuclei also represent the highest centers at which

the processing of neural stimuli corresponds to auditory information obtained from just one ear. From the cochlear nuclei, auditory information is processed by the superior olivary complexes, the lateral lemnisci, the inferior colliculi, and the medial geniculate bodies. Impulses are finally transmitted to the cortex by the auditory radiations. Owing to the numerous decussations at higher centers, there is representation of each ear on both sides of the brain, with greater representation on the opposite side.

Caution should always be exercised when an audiologist attempts to determine the site of a lesion affecting the auditory system. A patient may, for example, have both a cochlear and a central disorder. Most auditory tests give results that reflect primarily the first lesion reached by the stimulus (the most peripheral lesion) but can be further complicated by the more central lesion. Ruling out one anatomical area of the auditory system should not result in a diagnosis of a lesion in a specific region elsewhere.

Both behavioral and electroacoustical/electrophysiological procedures have been devised for testing central disorders, but none has been demonstrated to be infallible. Much research is needed to improve techniques for detecting disorders in the central pathways and pinpointing the area of damage. There is little doubt that this is one of the most challenging areas for research in diagnostic audiology. Thirty-five years ago, Williford (1977) lamented that audiology had only scratched the surface in its efforts to diagnose APD and that practical treatment programs were even less developed. Despite considerable progress to date, these are areas that still need much additional exploration.

REVIEW TABLE 12.1 Audiological Symptoms of Retrocochlear Lesions

<i>VIIIth Nerve and Cochlear Nucleus</i>	<i>Central Pathways</i>
Decruitment; no recruitment	Poor binaural fusion
Marked tone decay at all frequencies	Low SSI-ICM scores
Rapid acoustic reflex decay	Low SSI-CCM scores
Elevated or absent acoustic reflexes	Increased Wave III–V interval
Marked increase in ABR Wave V latencies	SRS for distorted speech poor in ear
Present otoacoustic emissions	contralateral to lesion
SRS for distorted speech poor in ear ipsilateral to lesion	

Study Questions

1. Sketch from memory the auditory pathways arising from the cochlea. Label the different waystations and specify, as far as you can, the functions of each.

2. Make a list of the possible causes of hearing disorders at each of the sites just named.

3. Draw an audiogram typical of an VIIIth nerve lesion. List the results of as many site-of-lesion tests as you can remember.
4. Why are lesions of the central auditory nervous system subtle and difficult to observe on standard audiometric tests?

5. List the tests that may be performed for central auditory lesions. Discuss the shortcomings of each test.

6. List the tests that can be done with evoked response audiometry and the areas of the auditory system assessed.

Suggested Readings

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Endnotes

1. For Theodore Schwann, German anatomist and physiologist, 1810–1882.
2. For Friedrich Daniel von Recklinghausen, German pathologist, 1833–1910.
3. Auditec of St. Louis (800-669-9065).
4. SCAN and SCAN-A available from The Psychological Corporation, Harcourt Brace Jovanovich 1 (800-228-0752).

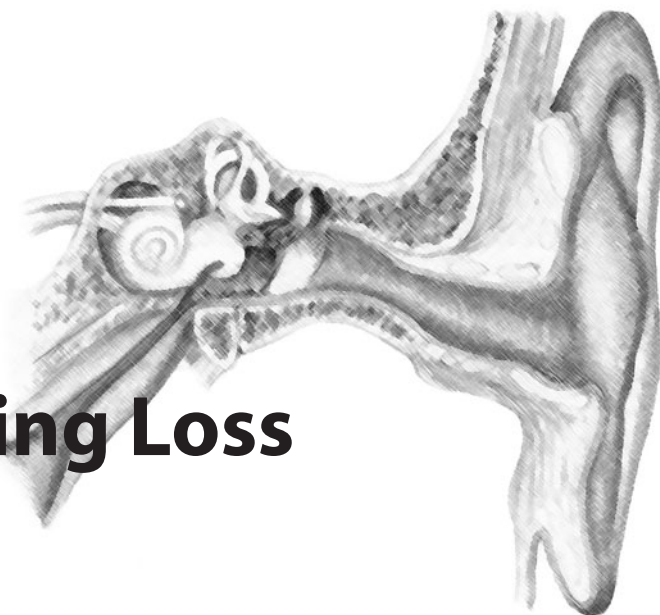
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CHAPTER 13



Erroneous Hearing Loss

PATIENTS WHO CLAIM TO HAVE HEARING LOSS, but actually have normal hearing or a lesser hearing loss than portrayed, are more than infrequently seen in audiology clinics. It is paramount that audiologists recognize these patients when they present themselves so that their cases may be properly managed. This chapter is dedicated to a discussion of this problem.

There are numbers of reasons why an individual might decide to fabricate or exaggerate a disability and many forms of expression for this decision. Lawsuits have been filed for compensation for whiplash, back pain, memory loss, cognitive deficits, spinal-cord injury, weakness, dizziness, and, of course, hearing loss. In addition, there is a host of litigious actions, many of which are related to claims for workers' compensation. Some children may express erroneous hearing loss as a means of acquiring peer acceptance, parental affection, decreased academic pressures, and so on.

The past four chapters have discussed anatomical areas in the auditory system and hearing losses associated with lesions in each of these areas. The term **erroneous hearing loss** (EHL) is used in this book to describe an apparent loss of hearing without any organic disorder or with insufficient pathological evidence to explain the extent of the loss.

The source of patient referral, medical history, symptoms, and behavior both during and outside of formal hearing tests are factors to be considered before making a diagnosis of erroneous hearing loss. Patients may exaggerate a hearing loss because they are incapable of more reliable behavior, because they are willfully fabricating or exaggerating a hearing disorder, or, perhaps, because they have some psychological disorder. There may, of course, be an interaction among these factors. Observation of the patient and special tests for erroneous hearing loss often lead the audiologist to the proper resolution of the problem.

LEARNING OBJECTIVES

This chapter should alert the reader to the problem of erroneous hearing loss and some of the symptoms that make its presence known. Following completion of this chapter the reader should be able to

- List several terms that have been used to describe erroneous hearing loss and recognize the implications behind these terms and why some may not be appropriate.
- Describe how some of the objective measures of hearing described in Chapter 7 may be applied to the evaluation of those with erroneous hearing loss, which tests may provide qualitative evidence (evidence of existence), and which provide a more quantitative measure of erroneous hearing loss.
- Outline tests using a standard two-channel clinical audiometer that can provide qualitative or quantitative evidence of erroneous hearing loss.

Terminology

There have been ongoing problems with the terms that audiologists and other specialists concerned with hearing disorders use to describe what is referred to in this book as *erroneous hearing loss*. Some other common terms that have been used are listed below:

- *Nonorganic Hearing Loss*. The term **nonorganic hearing loss** has been popular for some time and is common in the literature. The problem with this label is that it may convey the notion that the entire hearing loss, as presented by the patient, contains no organic explanation. Since many erroneous hearing losses have at least some physical basis, with added embellishment, the term leaves something to be desired.
- *Pseudohypacusis*. Some clinicians prefer **pseudohypacusis** (Carhart, 1961), which literally means “false hearing loss.” Originally spelled pseudohypoacusis, this word suffers from the same limitations as nonorganic hearing loss. The objection comes from the notion that the patient has no organic pathology whatsoever (Mendel, Danhauer, & Singh, 1999; Stach, 2003; Ventry & Chaiklin, 1962). The correct medical parlance implies that there is either no underlying pathology or that any present disorder does not explain the extent of a hearing loss (Roeser, Buckley, & Stickney, 2000). This meaning is not always conveyed in reports by audiologists.
- *Functional Hearing Loss*. Another term, **functional hearing loss** (Ventry & Chaiklin, 1962), is often used by physicians and psychologists to describe the symptoms of conditions that are not organic in nature. One of the many problems with this term is that it can be viewed from its other definition, which relates to some kind of function or malfunction.
- *Psychogenic Hearing Loss*. Some audiologists have used **psychogenic** (beginning in the mind) **hearing loss** to describe a fabricated or exaggerated problem of unconscious origin, as opposed to one that is consciously feigned. More recently this has been replaced by **conversion disorder**, because the underlying process is one of psychological stresses being converted to overt physical symptoms (Shahrokh & Hales, 2003). Both psychogenic hearing loss and conversion disorder speak to the etiology of the problem and should be eschewed by audiologists for a number of reasons.
- *Hysterical Deafness*. An older term, **hysterical deafness**, is a carryover from the Freudian era and is overly simplistic. This is in part true because of the all-or-none implications and the

suggestion that the behavior is entirely on an unconscious level. Martin (2009) has stated, “Since the word ‘hysterical’ derives from the Greek ‘hystera’ (womb) the term is actually pejorative and its disuse is appropriate for this reason as well.”

- **False or Exaggerated Hearing Loss.** Peck (in press) suggests that **false or exaggerated hearing loss** be used when the audiologist observes inconsistencies in test results or in patient behavior. Since this is a new term, only time will determine whether it will be widely adopted. This term is an improvement over the older ones, but since “false” may be considered to mean entirely false (fabricated) or partially false (exaggerated), it has some limitations.
- **Factitious Disorder.** The human psyche is far too complex for a simple contrast between intentional and unintentional motivations. Austen and Lynch (2004) discuss the use of a number of paradigms as alternatives to the dichotomy that exists in the traditional attempts to separate behavior into that which is deliberate versus that which is not. They advocate for another term, **factitious disorder**, and recommend a new nomenclature in dealing with the categorization of erroneous hearing losses. It is recognized that persons who deliberately pretend to have a disorder that they do not have, such as hearing loss, are not necessarily free of psychological influences. While complex, many of these recommendations appear valid.
- **Malingering.** One term probably used far too often is **malingering**. A malingerer is a deliberate falsifier of physical or psychological symptoms for some desired gain. Malingering is also frequently suspected (often unjustly) in association with automobile and industrial accidents, when payment may be involved to compensate patients for damages. Many patients who are called auditory malingerers actually have some degree of hearing loss. In addition to the potential for psychological damage to the patient and the risk of inaccuracy in diagnosis, calling someone a “malingerer” is tantamount to calling him or her a liar, which brings with it potentially serious litigious implications.

1. It is currently considered unscientific to separate the cause of inaccurate test results as being either _____ or _____.

Although erroneous hearing loss is the term used in this book, the reader should be aware of other terminology and should know that this label does not suggest cause, as do terms like malingering or psychogenic. There is no way to know for certain whether a patient with a feigned or embellished disorder is malingering, has a psychological disorder, or exhibits a combination of the two. Unless the patient admits to lying, or the confirmed diagnosis of an emotionally induced disorder is made by a qualified psychologist or psychiatrist, audiologists should settle for more general terms. In any event, terminology should be chosen carefully when communicating with patients, their families, or referral sources (Snyder, 2001).

Patients with Erroneous Hearing Loss

Patients manifesting symptoms of erroneous hearing loss may be of any age, sex, or socioeconomic background. It is probable that more adult males have been suspected of this disorder because emphasis has been placed on eliminating its possibility among men applying to the Veterans Administration for compensation for hearing loss.

Most of the studies performed on patients with erroneous hearing loss have been carried out on adult males because they have been “captive audiences,” as in military studies. This leads one to wonder whether there are any age or gender differences in this respect, and the paucity of data along

these lines regarding erroneous hearing loss is not helpful. Some generalizations to erroneous hearing loss may be made, however, from the literature on interpersonal communication.

Some erroneous hearing losses may be looked on as one form of deception, which can be defined as an intentional, conscious act. According to Burgoon, Buller, and Woodall (1989), in general, men find deceit more permissible than do women. They further claim that when women lie, it is usually to protect significant others, whereas men who lie tend to do so for more self-serving reasons. Because children's abilities to plan and execute deception successfully improve with age as they develop strategies for this purpose, we may assume that young children are less likely to feign a hearing loss successfully than are adults or older children. However, there are reasons to believe that erroneous hearing loss may be more common in children than has previously been thought and that the dynamics that result in such behaviors may be much more deeply seated than has been supposed (Johnson, Weissman, & Klerman, 1992). Erroneous hearing loss in children may signal long-term emotional problems (Brooks & Goeghegan, 1992) or serious distress (Riedner & Efros, 1995).

2. Malingering may be defined as _____.

The only true way to discover the kinds of strategies patients with erroneous hearing loss use in attempts to deceive their examiners is to ask them. This is obviously impossible, so Martin, Champlin, and McCreery (2001) studied 30 adults with normal hearing and paid them according to how diligently they tried to malingering a hearing loss on the usual routine tests. Based on their findings, malingerers may incorporate a combination of strategies to feign a hearing loss. For example, they may initially not respond to stimuli at all or randomly respond but then switch to a loudness judgment, responding to a predetermined reference level of loudness. According to this study, the majority of subjects who use more than one strategy use a combination of loudness judgment and a counting method. Specifically, malingerers may use the *loudness judgment* strategy for the evaluation of the first ear and then switch to the *counting with a loudness reference* strategy. For the evaluation of the first ear, the malingerer may simulate a hearing loss by responding to a predetermined reference level of loudness. Once the patients figure out the standard presentation procedure, they may switch to the counting strategy for the evaluation of the other ear. That is, they may simulate a hearing loss in the second ear tested by responding to every third presentation following the predetermined loudness reference. This type of combination exemplifies the importance of not adhering to standard procedures when erroneous hearing loss is suspected.

Ross (1964) has described the development of erroneous hearing loss in children under some circumstances. Very often, children with normal hearing inadvertently fail screening tests performed in public schools. There are many reasons for failure to respond during a hearing test besides hearing loss: Equipment may malfunction, ambient room noise may produce threshold shifts, students may have difficulty in following instructions, and so on. Children may find that as soon as school and parental attention focus on a possible hearing problem, they begin to enjoy a degree of gain in the form of favors, excuses for poor grades, and special attention. By the time some children are seen by hearing specialists, they may be committed to perpetuating the notion that they have hearing losses. Ross believes that public school referrals to audiologists or physicians should be made only after the individual responsible for the screening is fairly certain that a hearing loss exists.

There are probably myriads of reasons why individuals might show erroneous hearing loss. If a patient is, in fact, malingering or deliberately exaggerating an existing hearing loss, the motivation may be financial gain. Other reasons may simply be to win attention or to avoid performing some undesirable task. Because the underlying reasons are more difficult to understand, this avoidance has been considered a form of **conversion neurosis**. Whatever the dynamics of erroneous hearing loss, they may be deeply enmeshed in the personality of the patient, and a cursory look at these dynamics in any single chapter must be recognized for its superficiality.



Indications of Erroneous Hearing Loss

3. True/False
Patients involved in litigation over the cause of a hearing loss usually have an erroneous hearing loss.

There are many signs that alert the audiologist to erroneous hearing loss. These include the source of referral, the patient's history, his or her behavior during the interview, and performance on routine hearing tests. Sometimes the symptoms of erroneous hearing loss are so overt that they are easily recognized, even by nonprofessional personnel. At times the patient with erroneous hearing loss is the comic caricature of a hard-of-hearing person, appearing to have no peripheral vision when approached in the waiting room, and so on. The audiologist should be alert for exaggerated hearing postures or extremely heavy and obvious reliance on lipreading. Many patients with problems related to erroneous hearing loss show no such easily recognized signs.

When a patient is referred to an audiologist with the specification that there is compensation involved, erroneous hearing loss immediately becomes a prime consideration. Such referrals may be made by the Veterans Administration, insurance companies, attorneys, or physicians. To be sure, only a small number of such patients show behavior consistent with erroneous hearing loss. The incidence of erroneous hearing loss in this group, however, is bound to be higher than in the general population.

Clinical Commentary

It is difficult to estimate what percentage of a clinical population may exhibit erroneous hearing loss, but surely its occurrence will vary depending upon the patients served by a particular audiology clinic. It has been estimated that nearly 25% of patients seen for evaluation in conjunction with applications for compensation for work-related hearing loss have some involvement with erroneous hearing loss. As patients of any age can find reason to exhibit an erroneous hearing loss, astute clinicians are always on the alert for this possibility.



Performance on Routine Hearing Tests

4. True/False
Unexplained discrepancy between the SRT and PTA is often the first symptom of erroneous hearing loss.

One of the first clues to erroneous hearing loss is inconsistency on hearing tests. The test-retest reliability of most patients with organic hearing loss is usually quite good, with threshold differences rarely exceeding 5 dB. When audiologists find differences in pure-tone or speech thresholds that exceed this amount, they must conclude that one or both of these measures is incorrect. Sometimes, of course, the cause of such inconsistency is wandering attentiveness, and bringing the matter to the patient's awareness solves the problem. In any case, the patient should be advised of the difficulty, and increased cooperation should be solicited.

One of the most common symptoms of erroneous hearing loss is incompatibility between the pure-tone average and the SRT. In audiograms that are generally flat, the agreement should be within 5 to 10 dB. If the audiometric configuration becomes irregular, as in sharply falling high-frequency hearing losses, the SRT may be closer to the two-frequency average, or even at or better than the best of the three speech frequencies. In older patients, or

those suffering from abnormalities of the central auditory nervous system, the SRT is sometimes poorer than the pure-tone average. When the SRT is better than the pure-tone average, without an explanation such as audiometric configuration, erroneous hearing loss is a strong possibility.

That the patient with erroneous hearing loss often shows inconsistencies between thresholds for speech and pure tones is understandable. If, for example, a person were malingering, the objective would be to respond consistently to sounds above threshold, as if they were at threshold. Patients must therefore remember how loud a signal was the last time they heard it so that they can respond when the sound reaches that same loudness again. This is why test-retest differences are often so revealing. Some patients with erroneous hearing loss have an uncanny ability to replicate their previous responses to speech or pure tones, but they fail in equating the loudness of the two. When spondee and pure tones are presented at the same intensities, the spondee may appear louder, probably because the energy is spread over a range of frequencies.

Performance on other than threshold tests is sometimes helpful in detecting erroneous hearing loss. Sometimes a patient with erroneous hearing loss, due to his or her lack of sophistication about audiology, will yield excellent word-recognition scores at 30 dB SL. Patients who choose to pretend to have poor speech recognition may merely count the number of words and remember how many were deliberately missed in order to be consistent.

Determination of acoustic reflex thresholds is discussed in Chapter 7, and the results of this test produced by different kinds of auditory lesions are described in Chapters 9, 10, 11, and 12. Except in cases of cochlear damage, the acoustic reflex threshold is expected to be at least 65 dB above the behavioral threshold. When the reflex threshold is less than 10 dB above the voluntary threshold, erroneous hearing loss is a probability (Lamb & Peterson, 1967).

Acoustic reflex testing will often turn up evidence of erroneous hearing loss even when it might not otherwise be suspected. Consider the case shown in Figure 13.1. This patient claims to have no hearing in his left ear and yet he presents with normal acoustic reflex thresholds whenever the reflex-activating signal is presented to his left ear, with either ipsilateral or contralateral stimulation. This, of course, is impossible if the hearing loss shown is genuine.

Another suggestion of erroneous hearing loss comes from the apparent lack of cross hearing in unilateral cases. Considerable attention is paid in Chapters 4 and 5 to contralateralization of pure tones and speech. When individuals feign a loss of hearing in one ear, without the knowledge of the phenomenon of cross hearing, they often give responses showing normal hearing in one ear and a profound (or total) loss in the other ear, exceeding the most extreme values of interaural attenuation (Figure 13.2A). A lack of cross hearing is especially noticeable for mastoid bone-conduction tests, where any interaural attenuation is negligible. In fact, a truly profound loss of hearing in one ear would appear as a unilateral conductive hearing loss. The air-conduction thresholds would be obtained from the non-test ear with about 55 dB lost to interaural attenuation (assuming supra-aural earphones; approximately 85 dB for insert earphones). The result would be the appearance of a fairly flat air-conduction audiogram of about 55 dB HL (again 85 dB HL if insert earphones are used), with bone conduction in the normal range (Figure 13.2B). The bone-conduction signals delivered to the poorer ear would be heard in the better ear at normal levels (0 to 10 dB HL), since there is virtually no interaural attenuation for bone conduction. A true total unilateral loss is demonstrated audiometrically with masking in the normal ear (note the masked symbols used on the audiogram) in Figure 13.2C. This book encourages the routine use of insert receivers for air conduction and forehead placement for bone conduction. When dealing with suspected

5. Strongly suggestive of erroneous hearing loss is the patient who shows a total or profound hearing loss in one ear with normal hearing in the other ear and _____ is not performed.

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IMMITTANCE									
NAME Last - First - Middle				SEX	AGE	DATE	EXAMINER	INSTRUMENT	
ACOUSTIC REFLEXES									
Frequency (Hz)	RIGHT				LEFT				
	500	1000	2000	4000	500	1000	2000	4000	
Ipsilateral (Probe same)		90	90			85	90		
Contralateral (Probe opposite)	85	90	90	85	90	85	90	95	
Audiometric Threshold	0	5	10	0	NR	NR	NR	NR	
Reflex SL									
Decay Time (Seconds)	10 ⁺	10 ⁺			10 ⁺	10 ⁺			

RIGHT					STATIC COMPLIANCE					LEFT			C ₂ = C ₁ - C ₃
Tymp. Width	M.E. Pressure	C ₁ Volume	C ₂	C ₃ Compliance	Tymp. Width	M.E. Pressure	C ₁ Volume	C ₂	C ₃	C ₂	C ₃	C ₂	
60	0	.50	1.2	.70	100	0	.60	.95	.35				

TYMPANOGRAMS

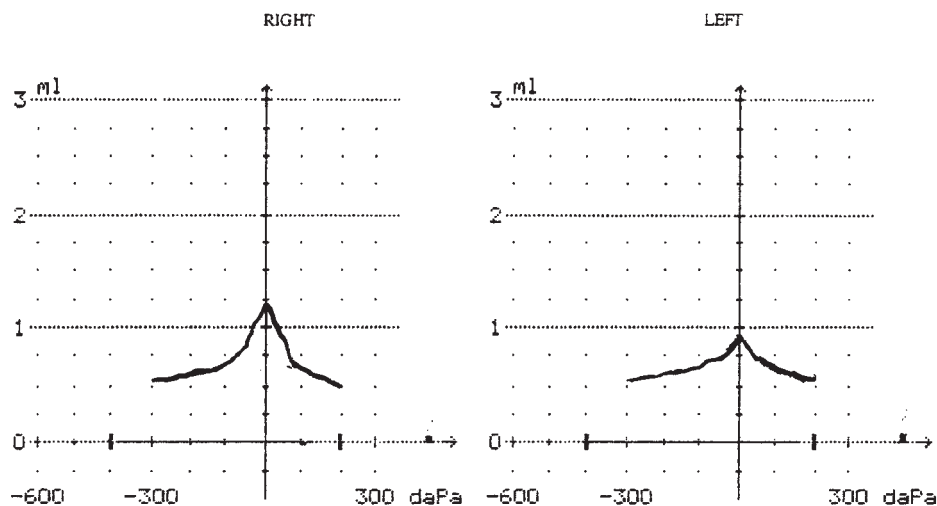


FIGURE 13.1 Theoretical results on immittance tests performed on a patient simulating a total loss of hearing in the left ear with normal hearing in the right ear. The tympanograms are normal for both ears, as are the acoustic reflex thresholds whether the reflex-activating signal is presented ipsilaterally or contralaterally, an impossible finding.

unilateral erroneous hearing loss, a switch to supra-aural earphones and mastoid bone-conduction placement may be useful.

Many audiologists have noted a peculiar form of response from some patients with erroneous hearing loss during SRT tests. Often these persons will repeat only half of each spondee at a number of intensities; for example, hot (for hot dog) or ball (for baseball). Why this occurs has not been explained, but it has been reported fairly often.

Suspicion of erroneous hearing loss is by no means proof. If it is suspected, it must be investigated further with great caution, using special diagnostic tests.

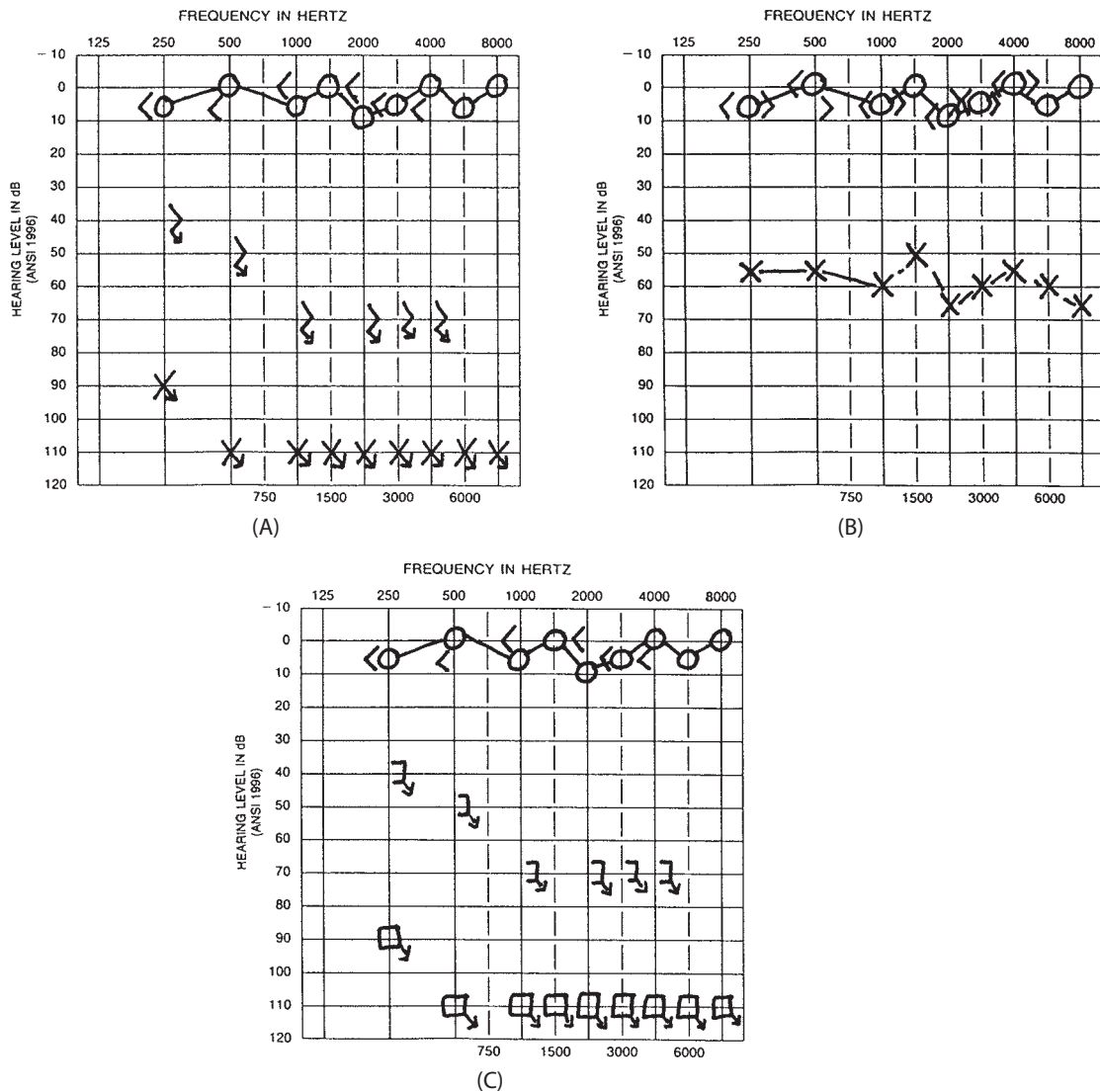


FIGURE 13.2 Theoretical test results showing normal hearing in the right ear and (A) a false total loss of hearing in the left ear (no evidence of cross hearing by air conduction or bone conduction); (B) a true total loss of hearing in the left ear showing tones cross heard in the right ear, giving the appearance of a conductive hearing loss; and (C) a total loss of hearing in the left ear with proper masking in the right ear.

Tests for Erroneous Hearing Loss

The primary purpose of special tests for erroneous hearing loss is to provide information about the patient's hearing, even though cooperation may be lacking. Behavioral tests for erroneous hearing loss may be performed with pure tones or with speech. Some tests may be carried out with the usual diagnostic audiometer, and other tests require special equipment. Unfortunately, many of the tests are merely qualitative; that is, they produce evidence of erroneous hearing loss, but do not reveal the patient's true thresholds of hearing. Other tests are quantitative and reveal information about the patient's actual thresholds.

Objective Tests

6. True/False
Objective hearing tests are so called because they require no subjective interpretation on the part of the examiner.

Nothing could be better suited to the testing of patients with erroneous hearing loss than procedures that require no voluntary responses. By determining auditory thresholds in such a manner, the very lack of required cooperation would tend to discourage some patients from attempting to malingering. Some tests are available that can be administered with this objective in mind.

Acoustic Reflex Tests. An addition to the many uses already described for acoustic immittance meters in Chapter 7 is a method of estimating hearing sensitivity for patients who are unwilling or unable to cooperate. Following up on some earlier work on differential loudness summation, Jerger, Burney, Mauldin, and Crump (1974) developed what has come to be known as the **Sensitivity Prediction from the Acoustic Reflex (SPAR)** test. Margolis (1993) has shown that, with this procedure, hearing losses in excess of 30 dB can be detected with sensitivity and specificity greater than 90%.

The SPAR test is based on the fact that acoustic reflex thresholds become lower as the signal bandwidth gets wider. Stated differently, to elicit the reflex, a normal-hearing person will require greater intensity for a pure-tone than for a wide-band noise. The usual difference is about 25 dB. Patients with sensory/neural hearing losses of mild to moderate degree show only a 10 to 20 dB difference, whereas patients with moderately severe losses show less than a 10 dB difference. Of course, patients with severe losses will show no acoustic reflex for either stimulus. To estimate the degree of hearing loss, the acoustic reflex thresholds (in dB SPL) at 500, 1000, and 2000 Hz are averaged and compared to the threshold for the broadband noise.

Auditory Evoked Potentials (AEP). The use of AEP audiometry, described in Chapter 7, lends itself nicely to examining many difficult-to-test patients, especially those with suspected erroneous hearing loss. Predicted thresholds obtained through some of these objective procedures have a close correlation with behavioral thresholds, allowing clinicians to discern both the hearing levels as well as the configuration of any existing hearing loss.



For a demonstration of the performance of auditory brainstem response audiometry, see the video titled "Auditory Brainstem Response" in the Clinical Demonstrations section on the Companion Website.

7. True/False
A patient showing an abnormal audiogram and normal OAE and ABR results should be suspected of having an erroneous hearing loss.

Otoacoustic Emissions (OAE). Transient-evoked otoacoustic emissions (TEOAE), also described in Chapter 7, may be of great value in the detection of erroneous hearing loss (Musiek, Bornstein, & Rintelmann, 1995). Gollegly, Bornstein, and Musiek (1992) presented six cases in which voluntary thresholds were elevated but TEOAEs were normal. Gollegly (1994) concludes that TEOAE can serve as a screening test for persons suspected of falsifying audiometric data, although if there is a possibility of a retrocochlear disorder, ABR testing should also be done. OAEs can be used to separate patients with hearing sensitivity better than 20 to 25 dB HL from those with hearing poorer than 30 dB HL. In such testing, transient-evoked OAEs are more sensitive for testing at 1000 Hz, while distortion-product OAEs are more sensitive from 4000 to 6000 Hz. The two appear equally sensitive for assessment of 2000 and 3000 Hz (Gorga et al., 1997; Prieve et al., 1993).

When otoacoustic emissions are normal and retrocochlear pathology is ruled out, a reasonable conclusion to draw is that patients with elevated voluntary thresholds are manifesting behaviors suggesting erroneous hearing loss. Absence of OAEs does not mean that some exaggeration of auditory threshold is not taking place. OAEs, like some other hearing tests that do not require behavioral responses, have been referred to as **objective audiometry**. These tests may be objective in the sense that patients do not play a voluntary role in stating when they hear a stimulus. Interpretation of responses, however, is at times a very subjective matter.

For a demonstration of the performance of otoacoustic emissions, see the video titled “Otoacoustic Emissions” in the Clinical Demonstrations section on the Companion Website.



Many behavioral tests for determining erroneous hearing loss have been developed over the years. Much like a lot of the behavioral site-of-lesion tests discussed in the historical note within Chapter 7, many of these tests have been replaced by the more objective measures just presented. Of the behavioral tests, the **Stenger test** is still widely used clinically, as it is highly reliable and easily performed using most clinical audiometers.

The Stenger Test. The Stenger test was designed for use with unilateral hearing losses. This test is based on the Stenger principle; that is, when two tones of the same frequency are introduced simultaneously into both ears, only the louder tone will be perceived. The test works best when there is a large difference (at least 25 dB) between the admitted thresholds of the two ears. Using a two-channel audiometer, a single pure-tone source may be split and controlled by two separate attenuators, or tones may be generated by two separate oscillators. If two oscillators are used, the tones must be locked in phase to avoid beats.

The thresholds of each ear for the desired frequencies are obtained first. Then, using one channel of the audiometer, a tone is introduced 10 dB above the threshold of the “better” ear. A response should always be obtained. A tone is then presented 10 dB below the admitted threshold of the “poorer” ear. A response will be absent for one of two possible reasons. The first, obviously, is that the patient does not hear it since it is below threshold. The second is that the patient may be unwilling to respond to a tone that he or she does in fact hear. At this point, both tones are introduced simultaneously, 10 dB above the better-ear threshold reading and 10 dB below the poorer-ear threshold reading.

If patients fail to respond, it is because they hear the tone in the poorer ear, which they do not wish to admit. They will be unaware of the tone in the better ear, owing to the Stenger effect, and so will not respond at all. This is called a positive Stenger. If the patient responds when both ears are stimulated, this is called a negative Stenger and suggests the absence of erroneous behavior, at least at the frequencies tested.

When positive results are found on the Stenger test, more quantitative information may be obtained. This is done by presenting the tone at 10 dB above the threshold for the better ear and at 0 dB HL in the poorer ear. With successive introductions, the level of the tone in the poorer ear is raised in 5 or 10 dB steps. The patient should always respond, because the 10 dB SL tone in the better ear provides clear audibility. If responses cease, the level of the tone in the poorer ear should be noted.

The lowest intensity that produces the Stenger effect is called the **minimum contralateral interference level**. This level may be within 20 dB of the actual threshold of patients with erroneous hearing loss. Although some clinicians always perform the Stenger test by finding the minimum contralateral interference level, use of the screening procedure described first in this section often saves considerable time when Stenger results are negative.

A negative result on the Stenger test is fairly conclusive evidence that there is no significant erroneous component in the “poorer” ear. A positive Stenger tells the audiologist that the threshold results obtained in the poorer ear are inaccurate, but it does not reveal the true organic thresholds, although they may be approximated by noting the minimum contralateral interference levels.

8. The Stenger tests are only suitable for patients with _____.

The Speech Stenger Test. Sometimes called the modified Stenger, the speech Stenger test may be carried out, using spondaic words, in exactly the same fashion as with pure tones. The principle is unchanged and requires that spondee words be presented by a two-channel audiometer. The SRTs are obtained for each ear, using channel 1 for one ear and channel 2 for the other ear. Spondee words are then presented 10 dB above the better-ear SRT, 10 dB below the level recorded as SRT of the poorer ear, and finally at these levels simultaneously. Criteria for positive and negative on the speech and pure-tone Stenger tests are identical.

Like the pure-tone Stenger test, the modified version for speech signals often helps to identify the presence of erroneous hearing loss but may not reveal the precise organic threshold of hearing. The speech Stenger test has the advantage over the pure-tone version in that there is no need for concern over the two tones beating. Determination of the minimum contralateral interference level for spondee words may be made to help in estimating the SRT.

The Doerfler-Stewart Test. Historically, one of the first tests for erroneous hearing loss, the **Doerfler-Stewart test**, capitalized on known test inconsistencies for threshold measures by testing with spondee words in the presence of noise, thereby exaggerating patient inconsistencies (Doerfler & Stewart, 1946). This is a confusion test and is rarely used today.

The Lombard Test. The **Lombard test** is based on the familiar phenomenon that people increase their vocal levels when they speak in a background of noise. If a noise is presented to the ears of persons who do not hear the noise, they will, of course, not change the loudness of their voices. If, however, the level of a person’s voice goes up as noise is added, it is obvious that the noise is audible to that person. The Lombard test is not a strong test for erroneous hearing loss and attempts at finding normal values—that is, how many decibels above threshold a noise must be to cause the reflex—have failed.

The Delayed-Speech Feedback Test. People monitor the rate and loudness of their speech through a variety of feedback mechanisms, for example, tactile, proprioceptive, and, primarily, auditory feedback. After a phoneme is uttered, it is processed through the auditory system, and the next phoneme is cued. Simultaneous feedback is essential for smooth articulation of speech sounds.

If a person’s voice is recorded on magnetic tape, delayed 0.1 to 0.2 seconds, and played back, this **delayed auditory feedback (DAF)** causes subjects to alter their speech patterns, in some ways creating an effect similar to stuttering. Speakers may slow down, prolong some syllables, increase their loudness, or find it very difficult to speak at all. The creation of delayed feedback audiometry was inevitable as a test for erroneous hearing loss, for surely a speaker’s voice played back with a short delay can have no effect on speech production unless it is heard.

For some, speech changes have been observed as low as 10 dB above the SRT while others can tolerate delayed-speech feedback at very high sensation levels with no apparent breakdowns in their speech or voice patterns. Possibly due to this variability, these tests have never gained wide popularity among audiologists.

The Pure-Tone Delayed Auditory Feedback (DAF) Test. The principle of delayed auditory feedback has also been applied to pure tones by presenting a brief tone (50 milliseconds) through the patient's earphone 200 milliseconds after the subject taps a silent switch with his or her index finger. The short delay from the tap on the key to the audibility of the tone causes subjects to modify the tapping pattern they are instructed to follow. If the tone is inaudible, tapping behavior continues uninterrupted. Ruhm and Cooper (1962) found that positive results on pure-tone DAF tests occur at sensation levels as low as 5 dB, thus the examiner may infer that the patient's hearing threshold is no poorer than 10 dB below the DAF threshold. Occasionally patients are seen who cannot or will not tap consistent patterns. In such cases the test cannot be performed.

Of all the tests described so far in this section, pure-tone DAF comes closest to doing what is necessary, identifying the patient's true organic thresholds. However, like delayed auditory feedback with speech, this test, too, has never gained high popularity among audiologists.

Variations on Békésy Audiometry Using a Conventional Audiometer. At this time very few clinics perform Békésy audiometry (described briefly in Chapter 7) as a routine procedure (Martin, Champlin, & Chambers, 1998). It was used to identify erroneous hearing loss when the pulsed-tone thresholds showed poorer hearing than the continuous-tone thresholds (called the Type V pattern) (Jerger & Herer, 1961), a phenomenon that is accentuated when the off-time of the signal is made longer (Hattler, 1970), when the intensity of the signal is decreased rather than increased (Chaiklin, 1990), or when some of these approaches are combined into a Békésy Ascending Descending Gap Evaluation (BADGE) (Hood, Campbell, & Hutton, 1964). This comparison of ascending- (using a continuous tone until audibility is signaled) and descending- (using a pulsed tone until inaudibility is signaled) threshold searches has also been described using a conventional audiometer and works quite well as a qualitative measure of erroneous hearing loss (Cherry & Ventry, 1976; Harris, 1958; Thelin, 1997; Woodford, Harris, Marquette, Perry, & Barnhart, 1997). Schlauch, Arnice, Lindsay, Sanchez, and Doyle (1998) recommend an ascending procedure for SRT and a descending procedure for pure tones to identify erroneous hearing loss.

Martin, Martin, and Champlin (2000) developed a procedure called **CON-SOT-LOT**, which stands for "continuous tone, pulsed tone with a standard off-time (50%), and a lengthened off-time (80%)." The procedure is carried out with an audiometer manually, depressing the interrupter every other pulse to create the lengthened off-time. It is also used in a descending format (beginning well above the patient's admitted threshold) and an ascending format (beginning at a level well below the patient's admitted threshold). All this totals six tests per frequency, but the test runs very quickly and has been found to be very difficult for patients exhibiting erroneous hearing loss to "beat." There clearly is evidence (Martin & Monro, 1975; Martin & Shipp, 1982; Monro & Martin, 1977) that knowledge about the principles underlying some audiometric measures may assist the patient in "beating" some tests. Some procedures are more resistant to practice or sophistication than are others. Audiologists must consider these factors in working with patients demonstrating erroneous hearing loss.

The Varying Intensity Story Test. Another way of confusing a patient who may have an erroneous hearing loss is to administer the **Varying Intensity Story Test (VIST)** (Martin, Champlin, & Marchbanks, 1998). The patient is asked to listen to a story in one ear, parts of which are presented above the admitted threshold (+10 dB SL) and parts below this level (−30 to −50 dB SL). The story is delivered so rapidly that it is difficult for listeners feigning a hearing loss to be certain what information was obtained that should and should not be admitted to. This test requires the use of a two-channel audiometer and a stereo recording of the story.

At the completion of the test the patient is given a short test. The story in Figure 13.3 has the advantage that the theme changes from a discussion of china (the dishes) to China (the country), when information presented at the softer level is included.

CHINA

PART I	PART II
PRESENTED ABOVE THRESHOLD	PRESENTED BELOW THRESHOLD
China,	
is well known for its delicate beauty	despite overpopulation.
Many popular styles of china exist today.	and its rugged terrain.
Patterns	
of flowers and geometric designs are equally common	cooking originating in
Hand-painted scenes	of beautiful gardens
can be found	landscaping
if one knows where to look.	in many modern Chinese cities.
China owned by your grandmother probably	of the natural beauty of China
	in many museums
	Books about
is quite different from modern china. The computer age	contain much misinformation, because early 20th century China
changed the way complex designs are printed	
	has arrived and
on modern china.	
	on all types of textiles. A new age has dawned

FIGURE 13.3 Sample of a varying intensity story test.

If the patient correctly answers any questions based on information presented below the admitted threshold, the conclusion must be drawn that hearing is no worse than the level at which that information was presented. This test can demonstrate graphically to patients that, if they are deliberately feigning or exaggerating a hearing loss, the examiner is aware of it.

Other Confusion Tests. Often tests are administered that are designed to confuse patients suspected of erroneous hearing loss in hopes they will abandon this behavior. A series of tones may be introduced above and below the voluntary threshold, and the patient may be asked to count the tones and report the number that was heard (Ross, 1964). This becomes a problem for patients with erroneous hearing loss, because they have to remember which tones they are willing to admit to hearing. The same procedure may be used to pulse the tones rapidly from one ear to the other in a unilateral case. The tones should be above the threshold of the “better” ear and below the admitted threshold of the “poorer” ear (Nagel, 1964).

The “yes-no” method, described by Frank (1976), is often useful in finding pure-tone thresholds for children. The child is instructed to say “yes” when a tone is heard and “no” when a tone is not heard. An ascending method is used. Many children falsifying test results will say

“no” coincidentally with tonal presentation below their admitted thresholds. This method is easy and fast and makes life simpler for the audiologist when it works. Naturally, the more sophisticated children are, the less likely they are to be tripped up by such an obvious subterfuge.

Erroneous hearing loss may be identified by a standardized test for lipreading ability (Utley, 1946). The patient may be seated facing the examiner through the observation window separating the patient room from the control room. Lights in the patient room should be dimmed to minimize glare. The patient wears the audiometer earphones and is given one form of the test, with the intensity set well below admitted threshold but above the level estimated as threshold by the audiologist. A different form of the test is given in identical fashion, but with the microphone switched off. Patients often do considerably better on the test when they hear, possibly because they are eager to prove they are good lipreaders.

9. A problem with most behavioral tests for erroneous hearing loss is that they fail to reveal

Management of Patients with Erroneous Hearing Loss

Openly confronting a patient demonstrating erroneous hearing loss rarely results in improved test validity. After all, cooperation is hardly forthcoming in the presence of hostility. Clinicians may advise the patient that test inconsistencies exist, but they may try to shift the “blame” for this to their own shoulders, using such explanations as “Perhaps I didn’t make it clear to you that you are to raise your hand even if the tone is very soft. You’ve been waiting until the tone is relatively loud before you’ve signaled. I’m sorry that I didn’t make this clearer before, but let’s try again.” This provides patients with an honorable way out, which they often take.

Silver (1996) provides guidelines for the management of a number of erroneous conditions, including erroneous hearing loss. Silver also urges the avoidance of confrontation and labeling but rather the supplying of benign explanations for the behavior. Veniar and Salston (1983) advise that the patient may be told that the inconsistency of test results may be more a matter of poor listening than poor hearing, which may have a better outcome in rehabilitation.

As may be seen from the preceding sections of this chapter, a number of tests for erroneous hearing loss are at the disposal of the audiologist. In most cases, it is not difficult to uncover erroneous hearing loss. Many tricks have been used. For example, audiologists may cover their mouths when speaking to patients who profess heavy reliance on lipreading. Patients may be given instructions through the audiometer below their admitted SRTs, such as “Remove the earphones; the test is over.” Any movement of the hands toward the receivers tells the audiologist that the patient has heard the instruction and reacted before realizing that it was below his or her admitted threshold.

The greatest problem in dealing with patients with erroneous hearing loss concerns the determination of the true threshold and how to manage these patients. If all patients with erroneous hearing loss were liars whose dishonesty is motivated by greed or laziness, perhaps the job would be easier. It is possible, however, that many patients with erroneous hearing loss may be deeply troubled. As stated earlier, some hearing losses may be entirely feigned, others merely exaggerated, and still others produced because of some emotional difficulty.

10. True/False
Direct confrontation with the patient is often the best way of resolving erroneous hearing loss.

Certainly an accurate test of a child’s demonstrated hearing loss is the goal of every audiologist, and further assessment, including possible electrophysiologic testing, will be needed for any child whose hearing status has not been determined behaviorally. However, accurate results

may be more readily attained through conventional means after the underlying erroneous behavior of a child has been addressed (Clark, 2002).

Children who maintain that a physical disorder exists often have a psychological need for the favorable attention they perceive may attend the disorder, and this need may require investigation before behavioral measures yield success. Often something is disturbing these children at home (e.g., a pending divorce), at school (e.g., a school bully or pressure for improved academic performance), or in the neighborhood. It can be quite beneficial to the child for the audiologist to talk with the parents about some of the possible reasons inaccurate test results have been attained. Parents should see their children in these circumstances as resourceful, not deceitful. It is indeed the clever child who can create circumstances that provide some psychological support when confronting significant life stressors (Clark & English, 2004).

An informal discussion with parents providing some “food for thought” on their child’s behavior is frequently all that is needed to set the stage for resolution of the erroneous behavior. It is the child who then continues to maintain the existence of hearing loss in the presence of contrary test findings that is of greater concern and who needs more than the services of an audiologist. In these instances, a counseling consultation with the school psychologist should be recommended. The supportive therapy that can be provided through this referral is often the most efficacious treatment for the child with erroneous hearing loss (Andaz, Heyworth, & Rowe, 1995).

One of the temptations that all professional persons must avoid in working with patients with disabilities is that of making value judgments. Although we may be curious about the psychodynamics of a given situation, we cannot assume the role of psychiatrist with a patient suspected of having a psychogenic hearing loss. We also cannot play prosecutor, no matter how convinced we are that a patient is malingering. Malingering can be proved without question only if the patient admits to it, and that is unquestionably rarely, if ever, seen.

When erroneous hearing loss is demonstrated, it may be an unwise practice to draw the audiogram. Too many persons are prone to glancing at the red and blue symbols, with no study of the actual results and what they mean. When suspicious results are observed, it may be better to write “suspected erroneous hearing loss” across the audiogram, to force anyone reading it to look more carefully at the report that should accompany the results of any hearing evaluation. In writing reports, audiologists should avoid the word malingering, but they should not hesitate to say erroneous hearing loss, if they believe this to be the case. Referrals to psychiatrists or psychologists are sometimes indicated, but they should be made very carefully. Exactly how a patient should be advised of test results is an individual matter and must be dictated by the experience and philosophies of the audiologist.

EVOLVING CASE STUDY

This chapter concerns special tests for erroneous hearing loss, a diagnosis that appears to fit Case 3. All that is present so far is a history and set of symptoms that appear to indicate that this patient, for whatever reason, is not reporting his ability to hear in an accurate fashion. The very first test tip-off was the lack of a shadow curve for all the threshold tests. If, in fact, the patient truly had no hearing in his left ear, his audiogram would not have appeared like the one in Figure 13.2A, but rather would have looked like Figure 13.2B, which indicates cross hearing for both air conduction and bone conduction and appears like a conductive hearing loss in the left ear. Because of the possibility of cross hearing, masking would have been carried out, and

the results would appear like those shown in Figure 13.2C. Therefore, results like those shown in Figure 13.2A are virtually impossible on an organic basis.

Since audiologists cannot read the minds of their patients, the true motivation in this instance cannot be known. An exception to this would be the highly unlikely possibility that the patient admits that he is malingering, that is, deliberately falsifying test results for external gain, in this case money. Many of the tests described in this chapter will assist in nailing down the diagnosis of erroneous hearing loss and possibly predicting the patient's true organic hearing thresholds. Before reading the comments below for Case 3, try to determine which tests you would use, in their logical order, and what the findings might be, assuming that this is, in fact, an erroneous hearing loss.

Case Study 3: Erroneous Hearing Loss

The most popular test for unilateral erroneous hearing loss is the Stenger test, both the pure-tone and speech versions. These tests would be expected to be positive in this case, and, if the minimum contralateral interference levels were as low as 30 or 40 dB HL, it could be predicted that the patient has normal hearing in his left ear. For the pure-tone test a number of frequencies should be tested.

A variety of tests are described in Chapter 12 that can be applied to this patient if additional evidence of erroneous hearing loss is required. Otoacoustic emissions (OAE) would take a short amount of time and could be carried out during the period allocated for a complete audiometric evaluation. In the presence of a positive Stenger test, if OAEs are normal in both ears, the hearing could be expected to be normal as well. Absent OAEs in the left ear might suggest that the patient is exaggerating a true hearing loss rather than fabricating it. Auditory brainstem response (ABR) testing is much more time consuming and would probably require rescheduling. If the results are similar for both ears on ABR, normal hearing might be concluded. A mild loss in the left ear is still a possibility.

Counseling patients with erroneous hearing loss is difficult and must be approached carefully. This delicate topic will be addressed in the case studies reviewed in Chapter 14.

Summary

Some patients seen in audiology clinics show symptoms of erroneous hearing loss. They may be malingering, exaggerating hearing losses, or exhibiting emotional disorders. There may also be other reasons for test results to be inaccurate. The responsibility of the audiologist is to determine the true organic thresholds of hearing, even if this must be done with less than the full cooperation of the patient.

A number of tests can be performed when erroneous hearing loss is suspected. Some of them merely confuse patients and provide evidence of erroneous hearing loss; they might also convince the patients that they must be more cooperative. Other tests actually help determine auditory thresholds.

Audiologists have an obligation to serve patients even when they are uncooperative. The problems of writing reports and counseling are much greater with patients with erroneous hearing loss than with those showing no evidence of this condition.

REVIEW TABLE 13.1 Summary of Tests for Erroneous Hearing Loss

Name of Test	Pure-Tone Signal	Speech Signal	Special Equipment Required	Tests for Unilateral Loss	Tests for Bilateral Loss	Estimates Threshold
ABR	X		X	X	X	X
Békésy Audiometry	X		X	X	X	
Confusion Tests	X	X		X	X	
CON-SOT-LOT	X			X	X	
DAF - Pure Tone	X		X	X	X	X
DAF - Speech		X	X	X	X	
Doerfler-Stewart		X			X	
Lombard		X			X	
OAE	X		X	X	X	X
SPAR	X		X	X	X	X
Stenger	X	X		X		
TEOAE	X		X	X	X	
VIST		X		X		

Study Questions

1. What are the first symptoms of erroneous hearing loss that you might notice? How do they manifest during a test and in a nontest situation?
2. Make a list of pure-tone tests for erroneous hearing loss. Separate them into groups according to ease of performance, necessity for special equipment, identification of threshold, and so on.
3. Repeat question 2 for speech tests.
4. Consider the concepts of malingering, exaggeration, and psychogenicity as they relate to hearing loss.
5. What are the advantages and disadvantages of acoustic reflexes, ABR, and OAE in the diagnosis of erroneous hearing loss?
6. How would you initially address a patient whose test results are not consistent with an organic origin? How might your approach differ for a child compared to an adult?
7. How might the motivations for erroneous behavior on a hearing test differ for a child versus an adult? What might you consider for a child who exhibits a persistent erroneous hearing loss before pursuing a recommendation for electrophysiologic evaluation?

Suggested Readings

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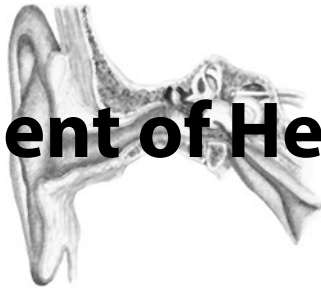
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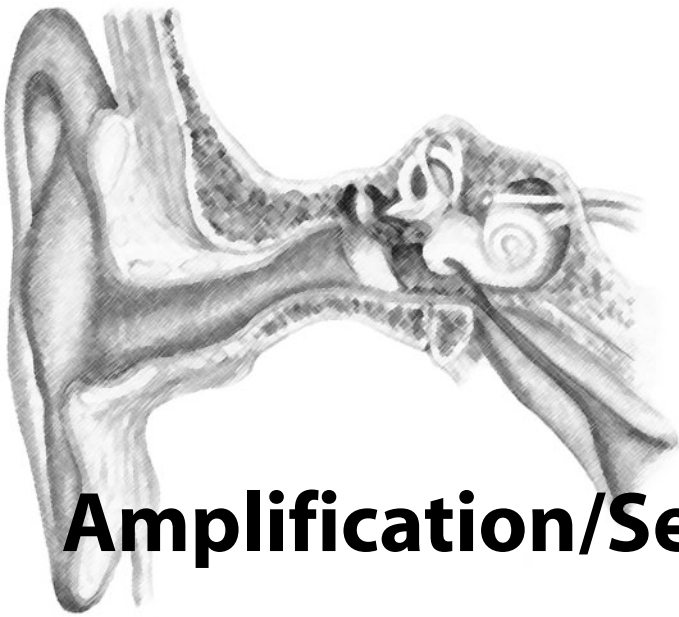
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PART IV

Management of Hearing Loss



he final part of this book is devoted to audiological management. All previous chapters on hearing disorders and their identification and quantification are of paramount importance to an audiologist's educational preparation and professional responsibilities because it is upon the information and skills obtained that the subsequent management of hearing loss rests. However, it is within the realm of treatment that audiologists provide to their patients where true autonomy can be found. These final two chapters present the thrust of what creates the independent audiology professional. Chapter 14 covers the subject of amplification/sensory systems and how they may be used to improve the communication of people with hearing loss. The closing chapter involves general patient treatment and is concerned with improving the lives of individuals with auditory disorders through specialized training and patient and family counseling.



Amplification/Sensory Systems

Amplification and sensory systems, either personal in the form of hearing aids or implants or supplemental in the form of assistive devices such as television amplifiers, comprise a major component of management endeavors for the patient with hearing loss. When audiological treatment is indicated, consideration should be given to amplification in the form of hearing aids. Although it is true that some patients cannot use or do not desire hearing aids, amplification should be considered for all patients with hearing impairment as part of a total rehabilitation program.

The task of the audiologist is to find the amplification/sensory system(s) most appropriate to the patient's needs and capabilities that will provide the greatest possible enhancement of speech understanding. This task becomes more challenging when working with very young children or individuals with multiple handicaps who cannot fully participate in the treatment process, those adult patients who deny the family's perceived need for treatment, or the elderly whose declining mental and/or physical capabilities impede the treatment process.

LEARNING OBJECTIVES

This chapter provides an overview of the evolution of amplification systems and the hearing aid styles and circuit options, including implantable options that are available at the opening of the 21st century. Upon completion of this chapter the reader should be able to

- Describe the differences between analog and digital hearing aids.
- Define the electroacoustic properties of hearing aids.
- Delineate the different styles of hearing aids.

- List the considerations taken within hearing aid selection and verification procedures for both children and adults.
- Recognize when assistive listening and alerting devices designed to augment the benefit derived through traditional amplification or to bring greater awareness of auditory signals may be useful and describe a variety of these devices.
- Describe the types of implantable hearing aids and who might be considered a candidate for implants.

Hearing Aid Development

Documentation of the historical development of devices to aid human hearing has been most fully chronicled by Berger (1988). The use of devices to collect and amplify sound for those with hearing loss may well be nearly as old as the human race. The earliest reference to sound collectors indicates that animal horns and seashells were employed to gather sound waves and direct them into the external auditory canal. While many other devices were contrived through the years to collect and direct sound energy (Figure 14.1), it was not until the late 19th century that the first electronic hearing aid was produced. Because of size and weight, early electronic hearing aids often limited their users to the proximity of a table that could support the devices. Although some early carbon hearing aids could be body-worn (Figure 14.2), it was nearly 40 years after the development of electronic hearing aids before the **vacuum tube** allowed for any significant miniaturization. The vacuum tube also brought a significant increase in power and frequency bandwidth so that electronic amplification became feasible for a larger range of hearing losses than could be reached with the earlier carbon instruments.



FIGURE 14.1 The Sexton Conversation Tube, an example of a sound collector for hearing enhancement. Presented by Samuel Sexton at the American Otological Society in July 1885. (From Berger, K.W. [1984]. *The hearing aid: Its operation and development*. Livonia, MI: National Hearing Aid Society. Reproduced with permission from the International Hearing Society)

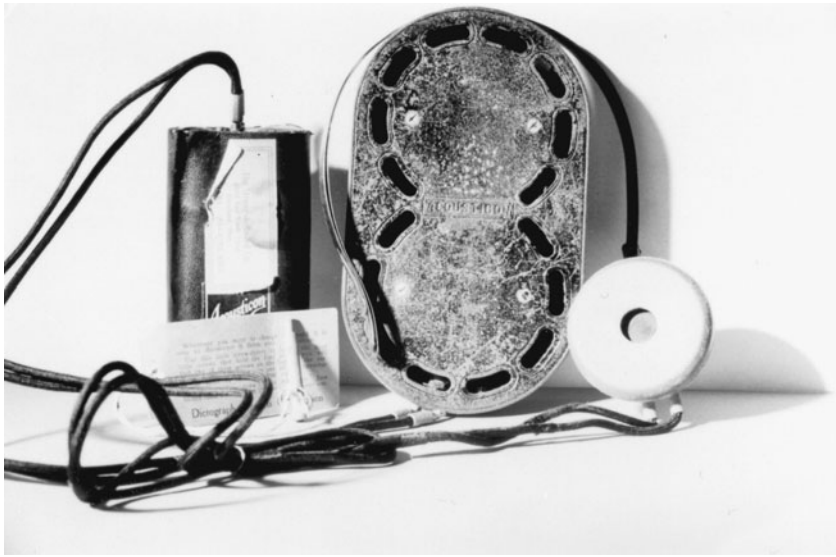


FIGURE 14.2 A complete carbon hearing aid consisting of a double carbon microphone for increased power, a receiver with headband, and battery, circa 1910. (Courtesy of John Hawks, Curator of the Kenneth W. Berger Hearing Aid Museum and Archives, Kent State University)

The first **transistor**, developed by Bell Telephone Laboratories in 1947, was not initially useful in hearing aid design. However, an early refinement, the germanium junction transistor, found its first commercial use in hearing aids. Because of the junction transistor's smaller size and lower battery voltage requirements, significant miniaturization of hearing aids rapidly followed. Hearing aids have continued to evolve and improve through the use of **integrated circuits**, computer technology, and increased miniaturization. For years, audiologists have found hearing instrumentation to be the most rapidly developing and changing aspect of their clinical practice. The profession can look for this trend to continue.

Hearing Aid Circuit Overview

Hearing aids may be thought of as miniature, personalized public-address systems. Sounds that strike the microphone (input transducer) are amplified, transmitted electrically to a miniature loudspeaker (output transducer), and then into the patient's external ear canal. Some hearing aids utilize a bone-conduction vibrator for the output transducer, and others are partially or fully implanted.

Hearing aids are signal processors: That is, they alter the signal input to improve it for the wearer. **Analog hearing aids**, so called because the electrical signals generated are analogous to the sound that comes into the instrument, have involved technology much like the grooves of a phonograph record resemble the sound waves that were used when the record was cut (Pascoe, 1991). Analog technology involves modifying a continuous electrical signal. In today's hearing aid market, analog hearing aids are seldom seen, being replaced by more sophisticated circuitry capable of providing greater benefits to those with hearing loss.

Completely **digital hearing aids** convert sound waves into numbers that are stored as binary digits (0s and 1s referred to as "bits"), the way a computer stores data. A digital instrument

1. True/False
Digital hearing aids
comprise close to 100%
of the hearing aids sold
in today's market.

changes the continuous electrical signal by means of an analog-to-digital converter (A/D) into a series of many separate bits, which represent the frequency, intensity, and time patterns of the signal. When a signal is in digital form, advanced processing operations can be carried out with lightning-fast speed. The altered signals are changed back to analog form by a digital-to-analog converter (D/A). Digital hearing aids are capable of providing improved clarity of signals and enhanced signal-to-noise ratios that are superior to those obtained with more traditional analog instruments. Digital technology has the potential to allow hearing aids to store sounds that enter the instrument and to separate wanted signals (those that will be used) from those that are unwanted (e.g., noise). Digital technologies allow separate amplifier characteristics to be stored into the hearing aid's memory, to be accessed by the wearer during different listening conditions (e.g., hearing in quiet, hearing in noise, listening to music) or that are activated automatically based on the types of sounds in the listener's environment. Digital hearing aid fittings comprise over 90% of hearing aids purchased (Kirkwood, 2006) and will be approaching 100% very rapidly. Nevertheless, despite the superiority of digital instruments, they should not be perceived by clinicians, or represented to patients, as panaceas.

A "hybrid" hearing instrument allows for the digital shaping of the sound response of the hearing instrument, while the actual processing of the signal is through analog technology. Referred to as "programmable" hearing aids, like their digital counterparts, these precursors to digital hearing aids could be coupled to computers and programmed more precisely to an individual's hearing loss configuration and loudness tolerance levels than analog hearing aids. While these instruments once were less expensive than fully digital instruments, they no longer carry this advantage and consequently have been replaced by the newer digital instruments.

In addition to the usual on-off switches and volume controls, even early-style analog hearing aids have internal and external adjustments to modify the amplification obtained in different frequency ranges, albeit not as precisely as their digital counterparts. All hearing aids can be manufactured with **compression** circuitry to reduce loud sounds and keep them within the patient's dynamic range. Because patient loudness discomfort levels are not increased by the amount of sensory/neural hearing loss, this circuitry is a valuable addition for those with loudness recruitment.

Another valuable addition to hearing aid circuitry is the directional microphone, which helps suppress sounds from behind a listener thereby increasing the signal-to-noise ratio of the desired signal. The advantages of directional microphones for listening to speech in noise is well documented (Amlani, 2001), and this feature is standard on most of today's digital hearing aids.

Some hearing aids also contain electromagnetic coils that, when switched into the circuit, bypass the microphone so that the user can hear more clearly over the telephone. These "telecoils" have been used for improved telephone communication systems for many years, and today all corded telephones must be compatible with hearing aids, and many cordless phones are as well. Given the early integration of telephone use into the lives of children today, parents should be fully instructed on the use of telecoils. In addition to telephone use, telecoils allow access to a variety of assistive listening devices. As such, Ross (2002) has recommended that this useful circuit be renamed "audiocoil."

One of the more revolutionary additions to hearing aid circuit options is the incorporation of Bluetooth technology to allow a wireless interface not only to computer programming software, allowing easier adjustment of amplification characteristics in the clinic, but also connectivity to other Bluetooth-compatible devices such as personal music players, televisions, land-line phones, and cell phones.

Depending on the desires of the patient, or the needs dictated by his or her physical limitations, many of the circuits in some of today's more advanced hearing aids can be set to function

automatically. Automatic audiocoils can switch themselves on when they sense a telephone is approaching the ear, and then switch back to the microphone circuit when the phone is removed from the ear. Hearing aids can “listen” to the level of sounds in the environment and automatically activate directional microphones as needed. Many of today’s hearing aids are dispensed without a volume control with compression circuitry that will automatically compensate for changes in the levels of incoming signals. In spite of the continued advancements in hearing-aid technology, in many ways they are becoming easier for the consumer to use.

Electroacoustic Characteristics of Hearing Aids

Hearing aids are usually described in terms of their electroacoustic properties, which include **output sound-pressure level (OSPL)**, **acoustic gain**, **frequency response**, and **distortion**. Until the **Hearing Aid Industry Conference (HAIC)** (1961, 1975), these characteristics were loosely defined, which led to a number of misconceptions. The most recent specifications for hearing aids are published by the American National Standards Institute (ANSI, 2003). Measurements are made on an artificial ear with a 2 cm^3 coupler to accommodate the external receiver of the hearing aid, or to hold the plastic tubing that comes from the receiver. Although the 2 cm^3 coupler measurement does not represent the hearing aid’s function in a real ear, it does provide a standardized system for comparing different hearing aids. Most modern audiology clinics utilize a special hearing aid test system (Figure 14.3) that



FIGURE 14.3 Hearing aid test system including sound chamber for 2 cm^3 electroacoustic analysis of hearing instruments and probe-microphone measurements. (Courtesy of Audioscan)

2. Hearing aids are usually described in terms of their _____, _____, and _____.

contains a sound-treated enclosure for the hearing aid, a sweep-frequency audio oscillator and loudspeaker, and a microphone that picks up the signal after amplification by the hearing aid so that a curve can be printed out showing the characteristics of the signal after amplification. In most test boxes, a graph is automatically drawn that shows the response of the hearing aid over a frequency range of 125 to 10,000 Hz.



For a demonstration of the use of a hearing aid test box, see the video entitled “Hearing Aid Test Box Measurements” in the Clinical Demonstrations section on the Companion Website.

Output Sound-Pressure Level (OSPL)

It is obvious that some control must be exercised by the manufacturer over the maximum sound pressure emitted from a hearing aid. If this pressure were unlimited, it could damage the wearer’s hearing. The output sound-pressure level (OSPL), previously called the *saturation sound-pressure level (SSPL)*, is the greatest sound pressure that can be produced by a hearing aid. The OSPL is considered one of the most important measurements and is usually made by using an input signal of 90 dB SPL with the hearing aid turned to full volume (OSPL90).

Acoustic Gain

The acoustic gain of a hearing aid is the difference, in decibels, between an input signal and an output signal. The gain (volume) control of the hearing aid is adjusted to its desired position, and a signal of 50 or 60 dB SPL is presented to the microphone. If the output SPL is 100 dB with an input of 60 dB SPL, the acoustic gain is 40 dB. **High-frequency average (HFA)** full-on gain is the average gain at 1000, 1600, and 2500 Hz when the volume control is turned as high as it can go. Although these measurements reflect maximum gain, they do not represent a true picture of the gain of the instrument on the patient, because hearing aids are rarely worn at full-volume settings. The ANSI (2003) standard is used for measuring acoustic gain below the aid’s full-on position. This **reference test gain** allows for a more realistic appraisal of the way hearing aids might perform on a patient, although anatomical differences among users can alter performance. The most accurate means to measure the gain an individual receives is through measures of increased sound-pressure level delivered by the hearing aid as measured at the tympanic membrane with a **probe-tube microphone**.

3. The acoustic gain of a hearing aid is the difference between the _____ and _____ intensities.

Frequency Response

The range of frequencies that any sound system can amplify and transmit is limited. In the case of hearing aids, this range is restricted primarily by the transducers (microphone and receiver) and by the earmold configuration. Modern ear-level aids can provide wider frequency response ranges than their predecessors because of advances in technology. The frequency response of a hearing aid is determined by first measuring the reference test gain over a wide frequency range. Figure 14.4 shows a tracing from an in-the-ear hearing aid that provides maximum amplification

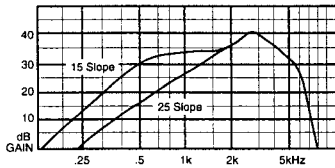


FIGURE 14.4 Frequency response characteristics of a typical in-the-ear hearing aid. Measurements were made with a 2 cm³ coupler and 60 dB SPL input level.

in the 1500 to 6000 Hz range. To determine the frequency response, a line is drawn parallel with the baseline, which is 20 dB below a level showing the average gain at 1000, 1600, and 2500 Hz. The points of intersection of this line with the response curve may be considered the frequency range of the instrument.

Distortion

When a sound leaving a hearing aid differs in its frequency spectrum from the input signal, **frequency distortion** has taken place. **Amplitude distortion** refers to the differences in the relationships of the amplitudes of the input and output signals.

When sounds of one frequency are increased in amplitude, they may cause the electronic or mechanical portions of an amplifying system to be overstressed. This **harmonic distortion** can be expressed as the percentage of distortion of the input signal. The greater the distortion of a hearing aid, the poorer the quality of the amplified sounds of speech.

4. Three types of distortion found in hearing aids are _____, _____, and _____.

Other Hearing Aid Parameters

Modern hearing aid test equipment allows for a number of other checks to be made on the characteristics of hearing aids. Some of these checks include **equivalent input noise level**, battery drain, the performance of telephone induction coils, and the dynamic characteristics of circuitry, which alter the gain of the hearing aid as a function of the input signal (**automatic gain control**). Although definitions and descriptions are not presented here, the interested reader is encouraged to check the suggested reading list at the end of this chapter.

5. True/False
The digital hearing aids of today are more stable than their analog counterparts largely negating the need for daily monitoring of children's amplification.

Clinical Commentary

Children with hearing loss need a high quality input of oral communication if they are to develop the essential phonological, morphological, lexical, and semantic features of spoken language. Yet for more than three decades, research has consistently demonstrated that more than half of all children with hearing loss attend their classes wearing ineffective hearing aids. Too often no one in the child's educational environment takes the initiative to ensure that a program of daily hearing aid monitoring is completed. Certainly a child should not begin a speech-language therapy session without a brief check of hearing aid function (Table 14.1). A daily visual and listening inspection of a child's hearing aids can be completed in less than 90 seconds by parents, teachers, or a child's speech-language pathologist (Figure 14.5). While vitally important, this check should not, however, be construed as a replacement for thorough periodic electroacoustic evaluations and hearing-performance checks.

TABLE 14.1 Common Hearing Aid Problems and Their Solutions

<i>Complaint</i>	<i>Explanation</i>	<i>Solution</i>
Weak sound	Partial obstruction in earmold**	Clean earmold
	Partial obstruction in tubing**	Clean/replace tubing
	Weak battery*	Replace with new battery
Intermittent sound	Broken cord***	Replace cord
	Weak battery*	Replace with new battery
	Dirty battery contacts	Clean contacts with cotton swab and alcohol
	Dirty controls	Move switches and controls through all positions to dislodge dirt; roll volume control several times through entire range; spray with contact cleaner.
	Internal	Return aid for servicing
No sound	Dead battery*	Replace with new battery
	Incorrect battery	Replace with proper battery
	Battery improperly inserted	Remove battery and replace correctly
	Obstruction in earmold**	Clean earmold
	Obstruction in tubing**	Clean/replace tubing
	Twisted tubing**	Untwist or replace tubing
	Broken cord***	Replace cord
	Broken receiver***	Replace receiver
	Set for telephone coil	Move to microphone position
	No explanation	Return aid for servicing
Aid works but is noisy	Acoustic feedback	Check for tight fitting mold
		Check connection between mold and receiver or earhook
		Check for properly inserted earmold
		Check for crack in tubing or earhook
	Internal feedback	Return aid for servicing

* Use a battery tester that places a “load” on the battery.

**Body type or CROS aid only

***Body type or bone-conduction aid only

Surprisingly, research has revealed that many elderly adults’ hearing aids are also operating at less than peak performance. Clearly speech-language pathologists providing services to adults who wear hearing aids should begin therapy sessions only after a check of hearing aid function. Those with malfunctioning hearing aids should be referred to their audiologists.

Bilateral/Binaural Amplification

A primary goal of any hearing aid fitting is to restore audition to as near normal a state as possible. As such, every attempt should be made to provide binaural hearing, assuming sufficient residual hearing and no contraindications presented by anatomical abnormalities. It should be noted that a bilateral hearing aid fitting does not assure binaural hearing, especially if significant asymmetries exist between the two ears. However, when aided binaural hearing is achieved, research has documented patient comments that speech is clearer, louder, and less contaminated by background noise. In addition, localization of a sound source is usually enhanced with



FIGURE 14.5 Visual and listening checks of hearing aids should be routinely conducted before hearing, speech, and language therapy and along with electroacoustic analysis of a hearing aid's performance, are an integral component of the audiologist's hearing-check procedures.

binaural hearing aids. The fact that evidence suggests a unilateral hearing aid fitting may result in auditory deprivation effects to the unaided ear (Gelfand & Silman, 1993; Silverman, Silman, Emmer, Schoepflin, & Lutolf, 2006) lends further credence to bilateral hearing aid fittings. Surveyed audiologists fit nearly 80% of their patients with two hearing aids (Strom, 2004). Carter, Noe, and Wilson (2001), however, report that some people with a preference for monaural fittings that cannot be explained by peripheral auditory findings demonstrated a left-ear deficit on dichotic digit tasks, suggesting a physiologic basis for this preference. In addition, in a small percentage of cases, speech recognition is so poor in one ear that bilateral aids decrease, rather than increase, the intelligibility of speech.

6. Binaural hearing refers to listening with _____ ears, while _____ indicates single ear listening.

Types of Hearing Aids

Hearing aids come in a variety of shapes, sizes, colors, and types. Among the hearing aids available today are the body-type, eyeglass, behind-the-ear, in-the-ear, in-the-canal, and completely in-the-canal instruments. Fully digital circuitry is available in even the smallest size hearing instruments.

6. both, monaural

Body-Type Hearing Aids

Body-type hearing aids (Figure 14.6A) are rarely used today, being reserved for patients with very profound hearing losses or those with handicapping conditions that deprive the individual of the neuromuscular control to support his or her head. These instruments contain the microphone, amplifier, circuit modifiers, and battery compartment within a case that may be clipped to the wearer's clothing or worn in a pocket or a special pouch. A cord carries the electrical signals to a receiver, which is coupled to the patient's ear through a custom-fitted earmold (Figure 14.7). Because instruments are now available that can be worn on the ear and still provide the power previously found only in body-type instruments, the use of body aids has dropped sharply.

Eyeglass Hearing Aids

Hearing aids built into the temple bars of eyeglasses were among the first attempts at head-worn amplification following development of the transistor (Figure 14.6B). The once-great popularity of eyeglass aids has diminished considerably in recent years, largely because of increased interest in in-the-ear hearing aids and the dissatisfaction of having to wear two prostheses in one, creating practical problems when one needs repair or replacement. Today, few manufacturers make or service this style of hearing aid.

Behind-the-Ear (BTE) Hearing Aids

Hearing aids worn behind the ear (Figure 14.6C) and coupled via a hollow plastic elbow, or "ear hook," to a molded plastic insert (Figure 14.7) can be used by patients with mild to profound hearing losses. While for some patients and degrees of hearing loss, BTE instruments are preferred, for many years they comprised only approximately 20% of hearing aids dispensed.

Open-Fit Hearing Aids

BTE hearing aids recently took a surge to well over 40% of the hearing-aid market (Kirkwood, 2006). This jump is almost entirely due to the recent emergence of a new breed of BTE instruments known as open-fit hearing aids (Figure 14.6D and E). These aids are often significantly smaller than traditional BTE instruments and are coupled to the ear with a very thin tubing, which adds to their cosmetic advantage. The open-designed ear tip, which frequently incorporates the hearing aid receiver within the ear canal, provides a more comfortable fit largely free of what has become known as the occlusion effect, the booming sound many hearing aid wearers complain about when listening to their own voices.

Because the ear canal is left largely open, increasing the likelihood of acoustic feedback, this style hearing aid's fitting range is limited to mild-to-moderate hearing losses. Problems with **acoustic feedback** generally become greater as hearing aids decrease in size or as the fitting becomes more open. Acoustic feedback is a whistling sound that is the result of a cycle caused by the amplified sounds leaving the receiver and reaching the microphone receiving repeated amplification.

7. A whistling sound known as _____ can limit the hearing aid style selection for some degrees of hearing loss.



(A)



(B)



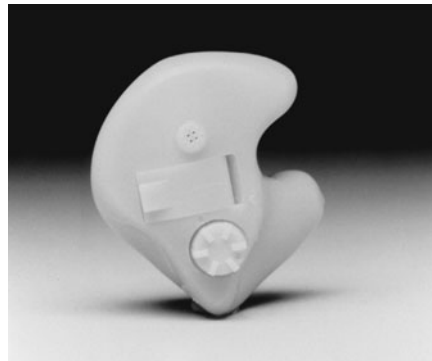
(C)



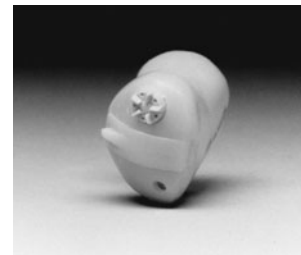
(D)



(E)



(F)



(G)



(H)

FIGURE 14.6 Types of air-conduction hearing aids: (A and B) the rarely seen body-type aid and eyeglass hearing aid with electronics housed in the paddle of the temple of the glasses; (C) behind-the-ear (BTE) aid; (D and E) Open-fit receiver in the canal hearing aid and the same hearing aid on the ear revealing its high cosmetic advantage; (F) in-the-ear (ITE) aid; (G) in-the-canal (ITC) aid; and (H) completely in-the-canal (CIC) aid. (A, C, G, and H courtesy of Rexton, Inc.; B and D courtesy of Starkey Laboratories; E and F courtesy of GN ReSound)

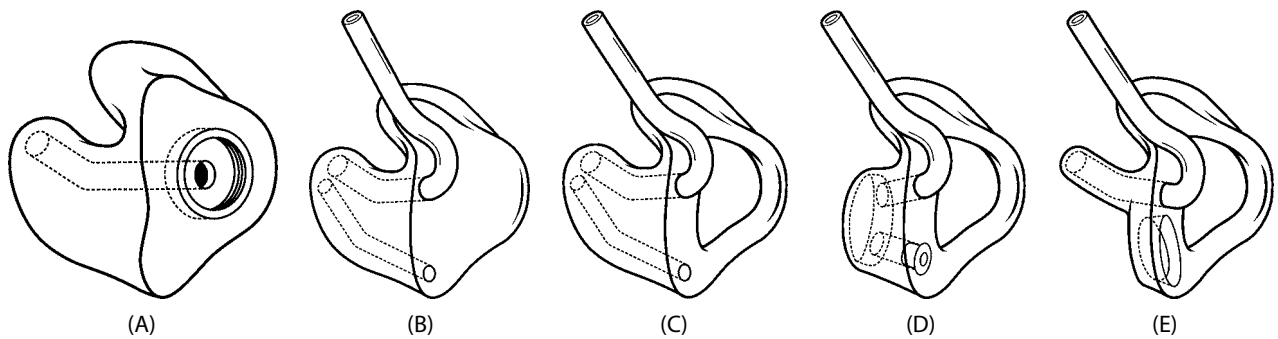


FIGURE 14.7 Five types of earmolds, showing (A) receiver type for use with external transducer, vented to reduce low frequencies; (B) shell type for severe impairment; (C) skeleton; (D) open-bore canal for enhanced high frequencies; (E) minimum contact mold for reduced occlusion effect. (Courtesy of Westone Laboratories, Inc.)

Receiver in Canal (RIC) Hearing Aids

Feedback is reduced by fabricating a tightly sealed ear piece and by moving the receiver as far from the microphone as is practical. Those who might prefer in-the-ear instruments may need to wear behind-the-ear hearing aids to decrease feedback to as great an extent as possible. Utilizing the smaller casings of the open-fit BTE hearing aids and a thin connector to the earpiece, RIC hearing aids were able to extend these cosmetically advantageous hearing instruments to a larger range of hearing losses. Feedback can also be substantially managed in many hearing aids with digital circuitry designed with feedback suppression capability.



For a demonstration of one procedure for taking custom earmold impressions for hearing aids, see the video titled “Earmold Impressions” on the Companion Website.

In-the-Ear (ITE) Hearing Aids

First developed in the late 1950s, instruments that are worn entirely in the concha and external auditory canal (Figure 14.6F) with the circuitry built into the earmold itself are still the most prevalent of the hearing aid styles worn within the ear. Originally useful only for mild hearing losses, because of improved technology they can be used for hearing losses that range from mild to moderately severe.

In-the-Canal (ITC) Hearing Aids

A major breakthrough in hearing aid design was the development of hearing instruments that fit entirely into the external auditory canal (Figure 14.6G), with only a slight protrusion into the concha. ITC aids are somewhat limited in power by their size, but with today’s feedback suppression circuits they can be used by some patients with losses in the moderately severe and severe range. This design takes advantage of the natural acoustic properties of the pinna, which are largely ignored by body, eyeglass, ITE, and BTE instruments. The smaller size of the canal hearing aids makes them less useful than the ITE aids for some elderly patients.

Completely in-the-Canal (CIC) Hearing Aids

The smallest style instrument available is the completely in-the-canal aid (Figure 14.6H), which is so tiny it is barely noticeable in many ears when it is inserted deep in the external auditory canal. Designed for mild or moderate hearing losses, the benefits of this instrument go beyond the obvious cosmetic appeal and include relatively easier use with telephones, lessening of wind-noise problems, increase of the usable gain of the instrument as the amplified sound is closer to the tympanic membrane, and maximization of the contributions to hearing made by the pinna and the concha. Despite its small size and deep fitting within the ear canal, frequently the cosmetic advantage for the CIC instrument is not as great as that for the open-fit style and RIC hearing aids.

While the benefits of directional microphones for enhanced signal-to-noise ratios can be achieved in cases as small as some of the canal-style hearing aids, size presently precludes the use of this valuable technology in CIC instruments. The smaller size of these instruments also requires smaller batteries, which must be considered when working with a patient with reduced manual dexterity. In addition, as with some of the canal hearing aids, coupling to assistive listening devices is not possible. These limitations may explain why sales of these cosmetically advantageous hearing instruments have dropped to only about 11% of all hearing aids dispensed (Kirkwood, 2006).

For additional hearing aid illustrations, see the “Hearing Aids and Assistive Listening Devices” section under Learning Supplements and the video titled “Hearing Aids” in the Clinical Demonstrations section of the Companion Website.



Single-Day-Fit Hearing Aids

Nearly 80% of those with hearing loss have yet to seek the treatment they need to improve their hearing. In an attempt to make hearing aids more appealing to this large, underserved population, inexpensive disposable hearing instruments were brought to the market in the 1990s. These instruments have a 40-day use-life (generally the life of the battery) and a price under \$100 for a binaural set. These products come with a variety of circuit options for the audiologist to select from and three sizes purported to fit a majority of adult ears.

It was hoped by those who produce these hearing aids, as well as those who dispense them, that they would appeal to the younger demographic of people with hearing loss who often have only mild to moderate hearing loss yet an active lifestyle and to those who are looking for an introduction to amplification because they may not be fully convinced that they have a significant hearing problem. While disposable hearing aids have experienced some success in Europe, they were not widely accepted in the United States. The more recently developed open-fit hearing aids offer the same single-day fitting of the disposable hearing instruments given that they require no impression of the ear and can be dispensed in one office visit, potentially granting it significant market appeal to the baby boomer generation.

CROS Hearing Aids

A patient with an unaidable unilateral hearing loss has a particular kind of listening difficulty, which can include trouble hearing soft speech from the “bad side.” Little had been done in the way of amplification for such problems until Harford and Barry (1965) described a specially built instrument called **CROS (contralateral routing of offside signals)**. In this configuration,

the microphone is mounted on the side of the impaired ear, and the signal is sent to the amplifier and receiver fitted at the side of the normal-hearing ear. The signal may be routed electrically through wires that are draped behind the head for BTE and ITE aids. The most popular method today is by way of FM transmitters and receivers, eliminating the need for wired connections. The signal presented to the canal of the “good” ear, either through a plastic tube or through a custom earmold, may contain an additional opening to allow unamplified sounds to enter the external ear canal normally. In this way patients hear from the “good” side in the usual fashion, but they also hear sounds from the “bad” side as they are amplified and led to the better ear.

The use of the CROS hearing instrument has expanded beyond its original intended use for unilateral hearing loss. It has been used both monaurally and binaurally (CRIS-CROS) for high-frequency losses and in other difficult cases in which traditional fitting results in acoustic feedback. A **BiCROS hearing aid** configuration allows for implementation of the traditional CROS principle, with the addition of amplification delivered directly to the better-hearing ear

when this ear also has some degree of hearing loss. Variations of the CROS system are available for different types of hearing losses (Dillon, 2001).

While the CROS feature can be valuable in eliminating the difficulties of hearing from only one side, difficulties with understanding speech in noise may continue, as all sounds are still received unilaterally. Indeed, Kenworthy, Klee, and Tharpe (1990) indicated that the introduction of additional noise into a normal, or near normal, ear might be a detriment to children in a classroom setting. Today, increasing numbers of patients with unilateral deafness consider use of bone-conduction implants as discussed later.

8. CROS hearing aids were originally designed for people with _____ hearing losses.

Bone-Conduction Hearing Aids

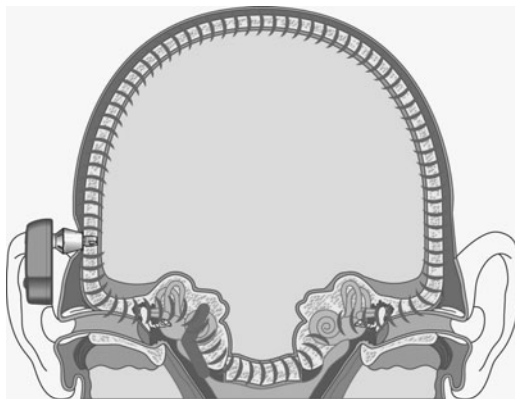
Bone-conduction hearing aids are selected for those patients with conductive hearing loss and otological conditions that preclude the use of air-conduction amplification (Figure 14.8). These conditions may include persistent or recurrent ear drainage or hearing loss resulting from congenital ear canal anomalies. The transducer is a vibrating receiver that is pressed firmly against the mastoid process. The transducer may be built within an eyeglass hearing aid or a post-auricular instrument worn with a headband, or coupled to a body-style hearing instrument. As vibration of the skull stimulates both cochleas from a single bone-conduction instrument, true binaural hearing, arising from timing and intensity differences of sounds reaching the two ears, is not attainable. Less than half a percent of all hearing aids prescribed are bone-conduction hearing aids.

Implantable Bone-Conduction Devices

There are many people who suffer from conductive hearing losses for whom surgery either has failed to improve their hearing or is not an option. A number of these people have been helped in the past by bone-conduction hearing aids, but these devices are often found to be uncomfortable and/or unsightly. Some patients have shown preference for a device that can be surgically implanted under the skin in the mastoid area. The procedure may be performed as outpatient surgery, using either local or general anesthesia. Several designs of such devices are now available (Figure 14.9) (Chasin, 1997; Miller & Fredrickson, 2000).



FIGURE 14.8 The vibrating receiver of a bone-conduction hearing aid sends sound waves to the cochlea through the bone-conduction auditory pathways of the skull. (Courtesy of Starkey Laboratories)



(A)



(B)

FIGURE 14.9 The Cochlear™ BAHA®, an osseointegrated auditory implant (Cochlear™ BAHA® BP 100 Bone Conduction System): (A) Bilateral routing of bone-conducted sound. (B) The BAHA attaches to an abutment connected to a titanium screw threaded directly into the mastoid bone allowing transmission of sound directly via the titanium screw. (BAHA® provided courtesy of Cochlear™ Americas, © 2010 Cochlear Americas)

For one design, a screw hole is prepared following a surgical incision in the mastoid, which is closed after the instrument is firmly screwed into place. After the incision has healed (about eight weeks), the patient is fitted with the induction device (which fits directly over the implant) and either an at-the-ear or body-worn battery-powered processor. Bone-conduction hearing implants statistically provide better performance than traditional bone-conduction hearing aids

(Christensen, Smith-Olinde, Kimberlain, Richter, & Dornhoffer, 2010). In addition, patients report good sound quality, elimination of the acoustic feedback found with traditional hearing aids, and preference for this device over their previously worn hearing aids (Ghossaini, Spitzer, & Borik, 2010; Johnson, Meikle, Vernon, & Schleuning, 1988).

Referring to implantable bone-conduction devices as hearing aids created confusion for patients in the past given that many private insurance carriers and Medicare do not provide coverage for hearing aids but do reimburse for the surgically implanted device known as either an “osseointegrated auditory prosthesis,” an “osseointegrated cochlear stimulator,” or simply a “bone-anchored hearing implant.”

Naturally, since hearing stimulation is by bone conduction, patients must have significant air-bone gaps and reasonably good bone-conduction thresholds in at least one ear. They are often used successfully with bone-conduction pure-tone averages as poor as 45 dB. Due to the successes demonstrated with early bone-anchored hearing implants, the FDA has approved its use for children as young as 5 years of age, for bilateral implantation, and for unilateral hearing loss (Spitzer, Ghossaini, & Wazen, 2002). In the case of congenital or sudden-onset unilateral deafness following autoimmune inner-ear disease or acoustic neuroma removal, a bone-anchored hearing implant can be placed on the deaf side, where it receives sound and delivers it through the bones of the skull (Transcranial Routing of Signal [TROS]) to the opposite ear’s normal-functioning cochlea (Wazen et al., 2003).

9. A bone-anchored hearing aid is also known as an _____.

There are some caveats for users of bone-anchored hearing implants. For example, the sound processors of these devices are more sensitive to damage from extreme weather conditions than are traditional hearing devices, or they can be extracted due to trauma.

While the implant itself, and the abutment, can remain in place, patients must have the processor removed before a magnetic-resonance scan can be performed. And just as with any amplification device, users of these instruments must take care around young children as batteries may be accidentally ingested.

Middle-Ear Implants

The impetus behind the development of middle-ear implants has been improved fidelity by driving the ossicles and/or cochlea directly without occlusion of the outer ear and reduction of acoustic feedback, because the energy is not transduced back to an acoustic signal. Designed primarily for moderate to severe sensory/neural hearing loss, these devices are increasingly being used with mixed hearing loss as well.

In August 2000, the first middle-ear hearing instrument received clearance from the Food and Drug Administration for commercial implantation in the United States for individuals 18 years and older (FDA, 2000). The device consists of three components: (1) an external audio processor that transmits sound across the skin to (2) an implanted receiver, which in turn transmits the converted electrical signal to (3) a transducer mounted onto the ossicular chain (Figure 14.10A & B). Newer, fully implantable devices will soon begin to be more common (Bassim & Fayed, 2010). With cosmetic advantages of some of the newer conventional hearing aids and the high cost of surgical implantation, it is unlikely that middle-ear implants would be employed for cosmetic reasons alone. The advantages of improved sound clarity, reduced feedback, and elimination of the occlusion effect have positioned middle-ear implants for continued growth in hearing rehabilitation (Spindel, 2002).

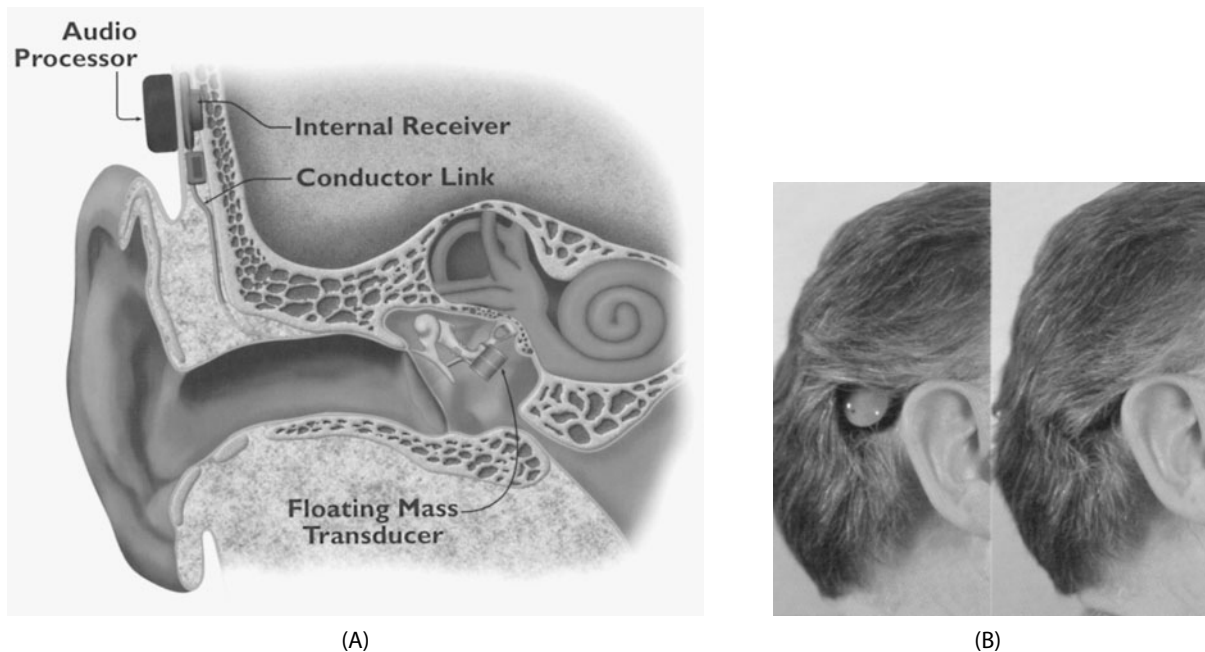


FIGURE 14.10 Middle-ear implant showing (A) anatomical cross-sectional view of device components and (B) physical appearance of the audio processor as worn. (Courtesy of Med-El Corporation)

Cochlear Implants

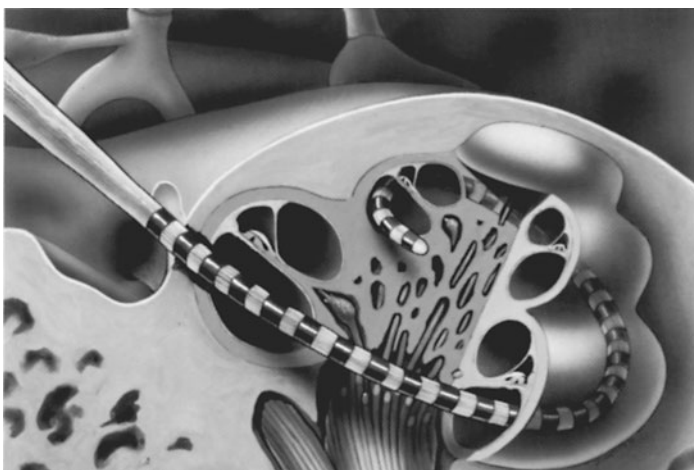
Early attempts to stimulate the cortex of the brain electrically to reproduce auditory sensations in people with profound sensory/neural hearing loss were abandoned for a variety of technical reasons, but they led to the development of several systems for electrical stimulation of the cochlea. Prior to cochlear implants, **vibrotactile aids**, designed on the principle that vibratory patterns can be generated on the skin that are directly related to the acoustic wave that strikes the microphone of the device, met with moderate success for those who could not use conventional amplification.

Studies demonstrate improved sound detection, enhanced perception of intonation, and greater speechreading performance through the use of vibrotactile stimulation (Auer, Bernstein, & Coulter, 1998; Galvin et al., 1991; Plant, 1998). Although less invasive a solution than cochlear implantation, vibrotactile aids fall significantly short of the positive results of cochlear implants and have never enjoyed a wide acceptance and use except when cochlear implantation is not a viable option.

In the absence of viable hair-cell function, the **cochlear implant** (House, 1982) allows for direct stimulation of the auditory nerves (Figure 14.11). The internal receiver, which is implanted under the skin behind the pinna, consists of wire electrodes and a tiny coil. Up to 22 active electrodes are placed 22 to 24 mm into the scala tympani within the cochlea (Figure 14.12A). Ground electrodes are placed outside the bony labyrinth, often in the temporalis muscle. A small microphone attached to an earhook feeds electrical impulses to a speech processor housed in a behind-the-ear casing, as in Figure 14.12B, or a body-worn unit similar to a body-style hearing aid. The processor codes the speech information, which is subsequently delivered to a transmitter, which converts it to magnetic impulses that are transmitted to the electrode array (Figure 14.12). An electrical signal is induced from the magnetic field in the cochlea and flows on to stimulate the auditory nerve.



FIGURE 14.11 Example of an ear-level cochlear implant device showing its internal components (Cochlear™ Nucleus® CP512 cochlear implant) and external components (CP810 Sound Processor and CR110 Remote Assistant). Nucleus® 5 photo provided courtesy of Cochlear™ Americas, © 2010 Cochlear Americas.



(A)



(B)

FIGURE 14.12 (A) Implantation of a multi-electrode array of a cochlear implant device. (Courtesy of Cochlear Americas) (B) Physical appearance of the cochlear implant processor as worn.

The external components of the device are actually not fitted to the cochlear implant recipient until four to six weeks after the surgery when healing is complete. After the external components are in place, the audiologist adjusts the stimulus parameters of the speech processor to most effectively transfer the temporal, frequency, and intensity cues of speech signals to the implanted electrode array. The subsequent program set for the speech processor is called a map. A fully implanted cochlear implant, with no external components, is anticipated to be available within a few years.

Only a small number of adverse effects from cochlear implant surgery have been reported, and many of these have been corrected with revisions in the instruments and surgical procedures. As the cochlear implant device was improved and diagnostic tests were expanded, candidacy for implantation grew to include children with profound congenital hearing losses. Today, the same number of children receive cochlear implants as adults, often with success that far exceeds that which could have been attained with even the best in traditional amplification. Regardless of how candidacy for cochlear implantation may change as future technology develops, several key questions as outlined in Table 14.2 must be addressed.

The degree of success with implantation will hinge on a variety of personal and support factors, but generally adults with post-linguistic deafness of shorter duration and children implanted before 2 years of age attain the highest levels of success. A cochlear implant is not a quick fix for any candidate. Adult cochlear implant candidates, as well as parents of children to be implanted, must be guided toward realistic expectations before the surgery itself and must be fully committed to the time and effort that will be required for success.

With the expansion of universal newborn hearing screening, increasing numbers of children at younger ages will be identified as potential implant candidates. Successful cochlear implantation with children is dependent upon coordinated interaction with a team of professionals working in concert with dedicated parents. A cochlear implant team may include an otologic surgeon, the child's pediatrician, a psychologist, an audiologist, and a speech-language pathologist, and/or an auditory rehabilitation therapist. The audiologist determines the audiological candidacy of potential implant recipients and is instrumental in the programming ("mapping") of the sound processor. The audiologist along with the speech-language pathologist and/or auditory rehabilitation therapist will serve as liaisons to the child's educational setting to help ensure the child's teacher(s) are familiar with the cochlear implant device and to provide needed educational recommendations.

Svirsky, Robbins, Kirk, Pisoni, and Miyamoto (2000) found that children deafened before 3 years of age who receive a cochlear implant and appropriate habilitation will maximize their chances of interacting within the hearing world. Indeed, Connor, Craig, Raudenbush, Heavner, and Zwolan (2006) found children implanted before 2.5 years of age had significantly stronger outcomes in consonant-production accuracy and vocabulary compared with age-matched peers who received

10. Cochlear implants are usually considered for people with _____ hearing losses.

TABLE 14.2 Is a Cochlear Implant the Answer? Questions to Be Addressed

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- Is implantation consistent with the patient's medical/health status?
 - Is implantation physically feasible (e.g., a viable auditory nerve and a patent internal auditory canal)?
 - Will implantation yield greater communication benefit than traditional hearing aids?
 - Will patients' psychological status, family dynamics, and educational and rehabilitation settings support successful implantation and the ongoing use of the device?
-

implants later. Nicholas and Geers (2003) reported much improved personal and social adjustment levels of young cochlear-implant recipients compared with previously reported adjustment problems among deaf children. The only remaining obstacle to pediatric implantation is the ethical considerations presented by those who question if others should make implantation decisions for children who are too young to choose whether they wish to try to live in a hearing world or reside within the Deaf community (Chute & Nevins, 2000; Lane & Bahan, 1998).

Adult implant recipients, as well as parents of pediatric recipients, are usually advised that they may not be able to discriminate among many of the sounds of speech. In spite of this, both objective and subjective outcome measures document the successes of cochlear implantation (Simons-McCandless & Parkin, 1997; Zwolan, Kileny, & Telian, 1997). Although frequency discrimination is far from perfect, voices may be heard at normal conversational levels, providing sound awareness and cues such as rate and rhythm that can assist the listener in speechreading. Many patients have reported that hearing their own voices allows them to monitor their vocal pitch and loudness much more effectively than was possible prior to implantation. A surprising number of patients demonstrate a marked ability to discriminate speech, even over the telephone. A growing number of cochlear implant recipients are also receiving the known benefits of binaural hearing through the appropriate fitting of traditional hearing aid amplification to the nonimplanted ear (Ching, Hill, Dillon, & van Wanrooy, 2004).

The American Board of Audiology has instituted a specialty certification for audiologists working with cochlear implant recipients. It is unfortunate that surveys indicate that large numbers of speech-language pathologists (in some surveys approaching 80%) receive no training in their education programs on the evaluation and treatment of children with cochlear implants yet may be required to provide services to these children who are on their caseload (Cosby, Culbertson, Hudson, Bengala, & Joyner, 2009). Clearly this area, just as so many areas in hearing loss management, requires a commitment from audiologists and speech-language pathologists toward life-long learning through continuing education.

Ongoing audiological management for those with cochlear implants includes programming the implant device parameters and monitoring its performance. For children too young to overtly respond to behavioral measures, performance evaluation can be attained through the electroacoustic measures discussed in Chapter 7 with stimuli delivered to the cochlear implant. In addition to assessment of improved hearing levels, periodic audiological evaluations assess improvement in sound and speech detection and the auditory reception of speech.

11. In order for a cochlear implant to be practicable, the _____ must be undamaged.

As experience with cochlear implants has increased and the design of the instruments has improved, the number of physicians doing implant surgery and the number and variety of recipients have increased. Because of reports in the news media, there is presently considerable interest in cochlear implants, and audiologists may be asked for information about them. It should always be pointed out that the cochlear implant is intended for those patients with hearing impairments so severe that they cannot be helped with other less invasive devices.

Auditory Brainstem Implants

Patients with bilateral acoustic neuromas that threaten either life or neurologic function are usually left with a loss of auditory function upon tumor removal. As they have no remaining cochlear nerve to stimulate, cochlear implantation provides no benefit. Advances in neuro-otology permit the cochlea and first-order neurons to be bypassed, permitting direct stimulation of the cochlear nuclei.

Only patients with **neurofibromatosis type 2**, 90% of whom exhibit bilateral acoustic neuromas, are eligible for auditory brainstem implantation (ABI) under protocols set by the U.S. Food and Drug Administration (Hitselberger & Telischi, 1994). However, future applications of ABI may include patients with bilateral temporal bone fractures or bilateral agenesis of the cochlea (Weber, 2002). As with cochlear implantation, the implanted electrode is coupled through a transcutaneous magnetic connector to an external sound processor. While ABI creates an enhanced auditory awareness and improved speechreading performance, communication improvement is not as great as that obtained for cochlear implant recipients, regardless of the extent of auditory rehabilitation received following implantation.

Vibrotactile Instruments

Despite all attempts to take advantage of residual hearing, some patients simply cannot be helped by any of the devices just described. There is clear benefit to the use of instruments that amplify sound, not to augment hearing per se, but to provide tactile stimulation on the surface of the skin. An interest in such stimulation continues because, unlike cochlear implantation, vibrotactile aids are noninvasive and thereby pose less risk to young children than surgery and because some cochleas are congenitally ossified and cannot be implanted.

Selecting Hearing Aids for Adults

The selection of appropriate hearing aids and the subsequent acceptance of their use is dependent upon a number of factors, not the least of which is the patient's motivation to follow the audiologist's recommendations. Clearly a comprehensive case history, assessment of the patient's perception of the impact of the loss, and a full diagnostic hearing evaluation are prerequisites to the selection of amplification, but none of these possess a clear predictive value of hearing aid use. A measure of the level of noise that patients are willing to accept when listening to speech may provide a greater indication of hearing aid use than any other of the audiologist's tests (Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, 2006). This "acceptable noise level" is expressed as the decibel difference between the most comfortable listening level for cold running speech and the maximum background noise level the listener will accept.

In the past, general guidelines were used for determining whether a given patient should try hearing aids. Today audiologists often find such rules confining and lacking in usefulness. An old common rule was to recommend a hearing aid if the average hearing loss at 500, 1000, and 2000 Hz exceeded 30 dB in the better-hearing ear. Restriction to this kind of guideline ignores a number of critical factors, such as age, duration of hearing loss, speech-recognition ability, audiometric contour, intelligence, vocation, education, financial resources, physical limitations, and, perhaps most important of all, motivation to use hearing aids.

Before the era of modern middle-ear surgery, most patients wearing hearing aids had conductive hearing losses. Because these patients usually had good word-recognition ability and tolerance for loud sounds, many physicians encouraged them to try hearing aids. However, patients with sensory/neural hearing losses were discouraged from wearing hearing instruments because of their greater difficulties with speech recognition and loudness tolerance. Complaints that the instruments merely amplified the distortion they heard, as well as problems with loudness

12. Possibly the greatest indicator of an adult patient's success with amplification is the patient's _____.

recruitment, led many clinicians to conclude that patients with sensory/neural hearing loss were often poor risks for amplification. It is unfortunate that this misperception lingers among many physicians, despite the numerous improvements in hearing aid electronics.

With advances in middle-ear surgery, the number of people with conductive hearing loss wearing hearing instruments has decreased, while the number with sensory/neural losses has increased. This latter fact is partly a result of improvements in the instruments and partly because of the influence of rehabilitative audiology. Selecting hearing aids for persons with sensory/neural loss involves much more than simply scrutinizing the audiogram and making a recommendation. In many cases an adjustment period of several weeks with new hearing instruments can be a determining factor.

Carhart (1946) described a procedure for hearing aid evaluation that was used for many years. This procedure included making measurements in the sound field using a number of different tests, performed both unaided and with a variety of different hearing aids. In addition to doubts about how replicable results with sound-field speech audiometry with hearing aids can be, other problems presented themselves, casting doubt on the validity of the traditional comparative methods. However, the goals for hearing aid selection stated nearly four decades ago by Carhart (1975) still hold true today. These goals dictate that the ideal hearing aid fitting should (1) provide a restoration of adequate sensitivity for speech and environmental sounds too faint to hear without hearing aids; (2) provide a restoration, retention, or acquisition of the clarity (including intelligibility and recognition) of speech and other sounds within ordinary, relatively quiet environments; (3) achieve the same when these sounds occur in noisier environments; and (4) ensure that higher intensity sounds are not amplified to an intolerable level. Today's electronics address these goals more effectively than at any time in the past.

To meet these goals, today's approach to hearing aid fittings is by prescription, followed by some means of verifying the performance of the chosen circuit. A variety of prescription methods are currently employed by audiologists to match, as closely as possible, the acoustic characteristics of the earmold and hearing aid to the acoustic needs of the patient. In addition to more sophisticated electroacoustic circuit modifications than previously available, through venting and special earmold designs low-frequency energy can be de-emphasized for patients with hearing losses that are primarily in the higher frequencies. Mid-frequency energy can be modified with acoustic dampers or filters in the tubing of the earmolds or ear hooks of the aids, and high-frequency energy can be enhanced with bell-shaped tubing or belled receiver openings. Many of the prescriptive calculations done today are completed by computer algorithms that select frequency/gain response characteristics, compression needs, and output limits based on entered threshold information and frequency-specific uncomfortable loudness levels.

Verification and Validation of Hearing Aid Performance for Adults

Audiologists have come to realize that, despite the important measurements made in hard-walled 2 cm³ couplers, the real ear behaves quite differently. Amplified sound-pressure levels in the human ear are not accurately represented by the artificial cavity. Astute audiologists also recognize that reliance on hearing aid laboratory fitting software calculations, which are based on the dimensions of the average adult human ear, can also falsely represent the accuracy of a hearing aid fitting. These realizations have encouraged the measurement of hearing aid characteristics within the external auditory canal of the patient with tiny probe microphones (Figure 14.13). Such verification measurements reflect not only the acoustic characteristics of the hearing aid, but also the natural individual resonance of the ear itself and the interactions among these effects (Mueller, Hawkins, & Northern, 1992). Verification with probe-microphone measures are unfortunately not attained by many audiologists, a practice that Palmer (2009) notes is not in keeping with established professional protocols.



FIGURE 14.13 A soft silicone tube is placed in the ear canal near the tympanic membrane to obtain probe-microphone (real ear) measures of the acoustic characteristics of the hearing aid as worn.

For a demonstration of a real-ear measurement system for hearing aids, see the video titled “Hearing Aid Real Ear Measurements” in the Clinical Demonstrations section of the Companion Website.



When the earmold of a hearing aid is placed into the external ear canal, its first effect is to act like a plug, creating an additional hearing loss and altering the natural resonance of the ear. This is known as the **insertion loss**. Therefore, the first job of the hearing aid is to overcome the hearing loss it has created and the way the natural ear properties have been altered. For these reasons *in situ* (in position) measurements are extremely valuable in determining such important considerations as the real-ear unaided gain, the real-ear aided gain, and the **insertion gain**. With the programming capabilities of digital hearing aids, it is possible to use probe-tube measurements to tailor the response of the hearing instrument more closely to the sound-pressure needs of the individual.

The suitability of amplification cannot be judged solely on the basis of how closely aided thresholds approximate normal threshold levels. It is often impossible to reach normal threshold levels or even a full audibility of the **speech spectrum** with some severe or profound hearing losses because of the constraints of acoustic feedback and loudness tolerance levels associated with some hearing losses (Table 14.3). Probe-microphone measures of hearing aid gain to assess audibility and hearing aid maximum output to prevent overamplification should be combined with aided sound-field speech recognition measures as the recommended verification protocol, because probe-microphone measures alone do not assess an individual's cognitive processing abilities.

Clinical Commentary

Before the widespread clinical availability of probe-microphone measures of hearing aid performance, sound-field threshold tests with hearing instruments were common and are still used in some clinics today. Thresholds measured both with and without hearing aids at a number of different frequencies show the **functional gain** at different frequencies. This procedure is fraught with a variety of weaknesses when practiced

TABLE 14.3 Aided Threshold Goals

<i>Average Hearing Threshold^a dB HL + Hearing Loss Descriptor^a</i>	<i>Average Aided Real Ear Gain =</i>	<i>Aided Threshold Goal^b (dB HL)</i>
–10 to 15	NA	NA
16 to 25	4 to 10	12 to 15
26 to 40	10 to 20	16 to 20
41 to 55	20 to 30	21 to 25
56 to 70	30 to 40	26 to 30
71 to 90	40 to 50	31 to 45
91+	46+	45 to 55

^a Average 0.5, 1, and 2 kHz re: ANSI-1989
^b Goal based on sensory/neural hearing impairment. Conductive and mixed hearing losses will tolerate more gain resulting in a lower threshold goal.
^c From Goodman (1965) as modified by Clark (1981)
NA = not applicable
(Clark, 1996)

with adults, weaknesses that are only magnified when attempted with children. Such testing in 5 dB increments at sound levels that do not activate a hearing instrument’s compression can give misleading information about the degree of amplification for conversational speech. In lieu of functional gain measures, measured gain values attained through probe-microphone testing may be extrapolated onto the audiogram for a visual representation of hearing aid gain.

It should be noted that verifying a hearing aid’s ability to meet prescribed goals of amplification does not ensure a patient’s favorable perception of benefit. Some formal means of validation that the patient’s perceived amplification needs have been addressed should be included within any hearing aid fitting process. This may take the form of a pre- and post-fitting administration of a hearing-loss-impact questionnaire or other self-assessment measure. It is unfortunate that many audiologists continue to fail to attain formal verification or validation of their hearing aid fittings.

A guided approach to the selection, fitting, orientation, and outcome assessment of amplification for adults is available on the American Academy of Audiology website at www.audiology.org/publications/documents/positions/adultrehab.

Selecting Hearing Aids for Children

The general goal of any hearing aid fitting is to provide for reception of soft, moderate, and loud sounds within a variety of environments while maintaining comfortable listening. Attaining this goal with children, especially those who may have a variety of coexisting conditions, presents a true challenge to the pediatric audiologist who must consider the hearing aid fitting within the context of each child’s circumstances (AAA, 2003).

A child who is mature enough to perform behavioral hearing tests and is found to be in need of amplification may be tested by modifying certain adult selection procedures. The absence of receptive language skills, of course, usually precludes the use of speech audiometry in pediatric testing. Sometimes it is realized that a small child needs amplification even though no behavioral audiometric results have been obtained. Digital hearing instruments provide the electroacoustic flexibility so that modifications can be made as further information is obtained about the child's hearing sensitivity.

Clinical Commentary

It is neither necessary nor ethically appropriate to delay a child's hearing aid fitting until full audiometric data have been determined. The earlier the age at which amplification through properly adjusted hearing aids can be provided, along with auditory training and speech-language therapy, the better the chances for development of normal language and intelligible speech and voice. At a minimum, prior to hearing aid fitting, low- and high-frequency, ear-specific hearing threshold data should be attained through auditory-evoked potentials as discussed in Chapter 7. Behavioral measures may be obtained for older infants and young children through visual reinforcement audiometry and condition play audiometry as discussed in Chapter 7. Those children for whom a full hearing profile has not been determined should spend some time during each communication therapy session being conditioned to play audiometry. No hearing assessment is considered fully complete until behavioral thresholds have been determined.

Verification and Validation of Hearing Aid Performance for Children

Using probe-microphone-assessment procedures commonly employed with adults to verify hearing aid performance fails to adequately verify hearing aid fittings with children. One reason for this is the significant variation in the resonance properties of a child's smaller external ear compared to the average adult's ear, upon which targets are based. If a single aided probe-microphone measure can be attained from a child, the difference between this measure and one obtained through a 2 cm³ hearing aid analyzer can be determined at discrete frequencies. Knowing the "real ear-coupler difference" in hearing aid performance can allow all further hearing aid adjustments and measures to be completed through the analyzer without the child's active cooperation. Expected aided performance can then be extrapolated from the measured data.

As with adults, verifying that hearing instruments are performing as desired in a clinical setting is not the same as demonstrating the benefits and limitations of hearing aid use. Toward this end, aided speech-perception measures should be attained at the earliest date. Speech audiometrics that may be used with children are discussed in Chapters 5 and 8. In addition, functional assessment questionnaires can be completed by parents and educators to assess the validity of pediatric fittings and to aid in further remedial planning for children (Anderson, 1989, 2002; Anderson & Smaldino, 2000).

13. True/False
Pediatric and adult hearing aid fittings should not be considered complete without measures of verification and validation.

Hearing Aid Acceptance and Orientation

One of the obvious requirements in deriving maximum benefit from pediatric amplification is to get children to wear their hearing instruments. There are several reasons why some children are resistant. They may find their hearing aids physically uncomfortable, acoustically unpleasant, or cosmetically unappealing. Whereas vanity forces many adults to select the least conspicuous instrument, children are often attracted by those that are brightly colored and appealing. Allowing children to participate in the choice of the color of the instrument and earmold, whenever possible, makes them partners in the selection process, rather than passive participants.

14. True/False

Best clinical practice dictates that hearing aid fittings for children should be postponed until a full diagnostic picture of hearing status has been attained for both ears.

There is no way to stress the importance of providing amplification to children, when indicated, at the earliest possible time. The notion that such action might be “too soon” is simply untrue. Children’s acceptance of amplification is critical to the success of rehabilitation, and their enthusiasm toward acceptance will vary considerably. The sudden presentation of loud, distorted, and unfamiliar sounds can be frightening to children. They may be confused and annoyed by the earmold or the hearing aids themselves. For the small child, there is no way for explanations to precede the wearing of hearing aids. The attitudes portrayed by the audiologist, speech-language pathologist, family, and others can make a great and lasting difference in children’s attitudes toward amplification. It is important that children not learn to use their hearing aids as instruments of punishment against their elders. Children have been known to pull hearing aids from their ears and throw them to the floor when they become angry with their parents.

Much of the stigma thwarting adult acceptance of wearing hearing aids was reduced by President Ronald Reagan’s hearing aid fitting in the early 1980s and President Bill Clinton’s hearing aid fitting in 1997. Because of this, along with the continued growth of the older segment of the population and the fact that more people than ever before can now be helped to hear better through corrective amplification, the number of hearing aids dispensed each year is well positioned for future growth. Clearly, hearing aid dispensing is a role for which audiologists in training should be prepared.



Handout material to support the adjustment to new amplification may be found under Professional Resources on the Companion Website.

Acceptance of amplification is highly dependent upon the provision of clear and complete instructions in the proper use and care of the instruments and the expected benefits and limitations of the selected hearing system. Table 14.4 outlines the primary considerations in orienting new users of hearing aids, be they adults or children and their caregivers.

The dynamic nature of hearing instruments and the devices used to adjust them and measure their performance is such that the technology will probably be changed and updated on an almost constant basis for the foreseeable future. Science has truly come to the assistance of the hearing aid user. Nevertheless, it is essential that patients themselves play active roles in the selection and maintenance of their hearing instruments (Figure 14.14).

TABLE 14.4 Hearing Instrument Orientation Topics for Adult and Pediatric Hearing Aid Users, Family Members, and Educators

- Cleaning and moisture guard of hearing aids
- Insertion and removal of hearing instruments
- Overnight storage of hearing aids
- Insertion and removal of batteries
- Battery life, toxicity, and storage
- Recommended wearing schedule
- Basic troubleshooting
- Telephone and other ALD coupling
- Basic hearing aid maintenance
- Hearing aid insurance, loss and damage policies, and loaner hearing aid programs
- Recommended follow-up and monitoring

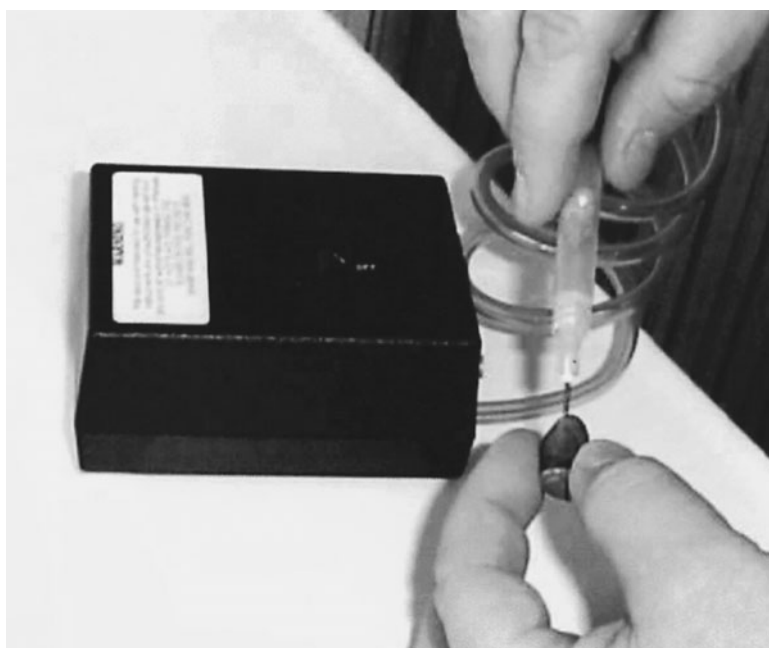


FIGURE 14.14 A hearing aid vacuum designed for home use to routinely suction cerumen accumulation from the receiver port of a hearing aid. Routine maintenance of hearing aids is integral to their successful use and long-term function. (Courtesy of JodiVac, LLC)

Dispensing Hearing Aids

Until the late 1970s, the bylaws of ASHA did not allow its members to dispense hearing aids directly. Such sales were considered unethical because it was felt that the audiologist's objectivity might be compromised if any profit motive were injected into the selection process. The tide of this entire subject has turned. Not only are audiologists in many practice settings dispensing hearing aids directly to patients, but university training programs have been preparing students for this practice for many years.



FIGURE 14.15 Earmolds and hearing aids can be ground and buffed when needed for greater physical comfort. The sound opening of the mold or hearing aid can be “belled” or scooped out to enhance high-frequency amplification and vent openings can be enlarged to decrease the amount of low-frequency amplification.

Under proper conditions, direct dispensing of hearing aids appears to be an ideal procedure. The audiologist must be (1) aware of the characteristics and adjustments of the aids to be dispensed, (2) able to provide simple repairs, (3) capable of taking earmold impressions and modifying earmolds (Figure 14.15), and (4) able to provide a total audiological treatment program suited to each individual's needs. In addition, direct dispensing provides the unique opportunity for a patient to receive an entire rehabilitation program from one highly trained professional. Before embarking on a hearing aid dispensing program, however, the audiologist must be aware of any pertinent state licensing laws. Many states now permit audiologists to dispense hearing aids without obtaining a second license through the hearing aid dispensers' licensing board.

Two separate professional groups dispense hearing aids in the United States. While some nonaudiologist hearing aid dispensers provide their services admirably, as a group they lack the professional training and expertise of the audiologist. The most efficient and successful means for a patient to procure hearing aids is through a professional qualified to

- Take a comprehensive case history and provide a full diagnostic hearing evaluation to determine the type and degree of any existing hearing loss and the existence of any possible otologic pathology necessitating medical attention.
- Select instrumentation based upon an individual's hearing loss, lifestyle, and listening needs.

- Modify the selected instruments' electroacoustic parameters to the most advantageous settings.
- Verify that the final settings address the acoustic needs presented by the hearing loss and determine that the benefit obtained is perceived as a true improvement by the patient.
- Fully orient the patient to the needed care and maintenance of the instruments and the requisite steps toward the adjustment to amplified sound.
- Determine with the individual and family what supplemental devices may augment the benefit derived through amplification.
- Provide communication instruction to offset the residual hearing difficulties that will always be present even with the most effective hearing aids.

It is unfortunate that consumers can purchase hearing aids through the Internet, bypassing the professional service component of the dispensing process. This approach to hearing healthcare, while appearing more cost effective, deprives many of the full hearing potential they might otherwise have received and runs the risk of failing to obtain treatment for a condition that may require medical attention.

Hearing Assistance Technologies

The inherent limitations of hearing aids often necessitate the use of a variety of technologies, including various **assistive listening devices (ALDs)** and vibratory or visual alerting systems. One of the major disadvantages of wearable hearing aids is the environmental noise between the microphones of the hearing aids and the talker, which creates adverse signal-to-noise ratios and decreased speech intelligibility. The closer the talker is to the listener's hearing aids, the fewer the effects of intervening room noise. In addition, reverberation and other acoustic characteristics of any room may affect important parameters of sound waves as they travel through air. Getting talker and listener close together in space is often difficult in classrooms, as well as in a variety of other listening situations.

Older auditory training units were hard-wired, meaning that the microphone and amplifier were physically connected to receivers worn by the listeners. This configuration severely restricted the person speaking to proximity to the microphone and limited the person listening to a fixed location at the receivers. There are three types of assistive listening systems commonly used today that interface in a variety of ways with personal hearing aids or small earphone receivers for use in classrooms, theaters, hospitals, houses of worship, auditoriums, retirement facilities, libraries, and personal offices and homes. These systems utilize transmitters and receivers that allow freedom of movement for the talker and the listener.

In a frequency modulated (FM) system, the talker wears a small microphone, and signals are transmitted along a radio frequency (RF) carrier wave. Receivers worn by the listener allow the signal to be demodulated and delivered to the user in a variety of ways, including an **induction loop** that is worn around the neck. With a neck-worn induction loop fitting, the signal is then amplified for the user via the telecoils/audiocoils within the hearing aids. In lieu of the induction neck loop, a wire from the FM receiver unit permits coupling directly to the hearing aids or through ear bud inserts or earphones (Figure 14.16C). Both of these means of coupling the FM receiver to the hearing aids are rapidly being replaced by

15. As presented in Table 14.3, aided threshold goals never fully approximate normal hearing. As such, many people with hearing loss benefit from additional hearing assistance technologies best known as _____.

16. Assistive listening devices can improve signal-to-noise ratios through direct transmission of the speech signal to the listener through _____, _____, or an _____.

technological advances that have permitted the miniaturization of the FM receiver, allowing the receivers themselves to be directly coupled to the hearing aids.

Speech may also be delivered directly to hearing aids through infrared systems (IR) that utilize light frequencies invisible to the human eye to carry speech signals to a receiving unit worn by the listener (Figure 14.16A). The receiving unit transduces the light signal into an auditory signal that may then be amplified to the desired level. Smaller infrared light systems may be used in the home for listening to television. Large-area systems may be found in cinemas, theaters, and houses of worship.



FIGURE 14.16 Examples of a few hearing assistance technologies for use by individuals with hearing impairment: (A) an infrared system for transmission and reception of auditory signals through invisible light frequencies, useful for the TV and in many live theaters and cinemas; (B) amplified cordless phone with caller ID; (C) FM system with microphones in both the transmitter and receiver for increased auditory signals, shown with earphones but also available with a neckloop that interfaces with hearing aid telecoils; (D) captioned telephone with text display used with the relay service; (E) smoke detector system that activates a bed vibrator for vibrotactile alerting; (F) amplified neckloop that picks up Bluetooth signal from a cell phone and creates an induction signal for the hearing aid telecoil. (Courtesy of beyondhearingaids.com)

A third system employs the same induction-loop principle used with the neck loop described earlier. In this system, an electromagnetic field is created by a loop of wire around the room. As with the neck loop, the user receives the signal via the telecoils/audiocoils within the hearing aids. Parts of Europe are far ahead of the United States in utilization of induction-loop technology. Overseas it is not uncommon to find banks, groceries, information kiosks, and other venues wired for sound reception through hearing aids' telecoils/audiocoils (Meyers, 2002, 2010). With this technology, hearing aid users standing on an electromagnetic induction pad can switch to their audiocoils to hear speech through their hearing aids while eliminating or greatly reducing all background interference. In 2006, the Gerald R. Ford International Airport in Grand Rapids, Michigan, became the first airport in the United States to utilize this technology. Induction loop systems are less expensive than either FM or IR systems, although some signal purity is sacrificed through electromagnetic coupling. A joint initiative started in 2010 between the Hearing Loss Association of America and the American Academy of Audiology to "loop America" should bring an increase in the use of induction loops in public places with a concomitant increase in hearing aid utility. Certainly, different systems may be more appropriate for different purposes (Ross, 2002; Tyler & Schum, 1995), but it clearly is time that audiologists proactively recommend telecoil/audiocoil circuitry for all of their patients.

In classrooms, either FM or IR technology can be coupled to sound-field speakers (Figure 14.17), providing greater acoustic accessibility of the teacher's instruction for all students in the room. Sound-field amplification must not be construed to be a replacement for a personal FM system. The former typically improves the classroom signal-to-noise ratio by 10 to 20 dB, the latter by as much as 20 to 30 dB. While some children's hearing losses require the greater signal-to-noise ratio provided through a personal FM unit, sound-field technology has proven beneficial for children with fluctuating conductive hearing loss, unilateral hearing impairment, and slight permanent hearing loss (10 to 25 dB HL), as well as those with language, learning, attention, processing, or behavioral problems (Flexer, 1999).



FIGURE 14.17 Classroom signal-to-noise ratios are enhanced as a teacher's voice is picked up by an infrared pendant microphone and transmitted to an IR speaker mounted on the wall to the left. (Courtesy of FrontRow)



FIGURE 14.18 A “personal communicator” amplifier to enhance communication in the absence of custom hearing amplification. The device may be plugged directly into the television set or other audio-output jacks to provide direct sound to the user’s ear thereby improving the signal-to-noise ratio. With a plug-in microphone, such devices can also be invaluable in helping to maintain more private conversations between healthcare providers and their patients in compliance with privacy legislation. (Courtesy of Williams Sound Corporation)

A valuable addition to the array of assistive listening devices is the personal listening system (Figure 14.18). Years ago, hearing aid laboratories strove to increase the cosmetic appeal of hearing aids by making them as small as possible. Today there are many people with hearing impairment who are willing to use a device that is clearly visible and allows patients and those speaking with them easy access to the unit, which is the size of a mini-audiocassette recorder, with large, easy-to-use controls. These devices are especially valuable in nursing homes, where looking after small hearing instruments can be a great inconvenience and where patients often lack the fine motor control required of smaller units. An increasing number of physicians are learning the value of personal-listening systems through audiologists. Confidential patient/physician dialogue is easily restored through these units for patients who have not yet been fitted with appropriate hearing aids.

Also included in the general category of hearing assistance technology are signaling or alerting units, which have been called “environmental adaptations” (Vaughn, Lightfoot, & Teter, 1988) (e.g., Figure 14.16E). The first of these devices amplified ringers of telephones and the talker’s transmitted voice. Subsequently developed devices alert individuals through flashing lights or vibrations to the presence of emergency signals such as smoke or fire alarms; crying babies; or such mundane but important signals as timers, doorbells, and alarm clocks. Additional

instruments to improve communication on the telephone include telecommunication devices for the deaf (TDDs), also known as text telephones (TTs) or captioned telephones (Figure 14.14D). All television sets larger than 13-inch models sold after 1992 are equipped with telecaptioning decoders to allow printed text to be viewed on the screen. Modern technology and microcircuitry have created instruments that can markedly improve the quality of life for those with a hearing loss.

For illustrations and descriptions of additional “Assistive Listening and Alerting Devices,” see the Learning Supplements section on the Companion Website.



EVOLVING CASE STUDIES

Chapter 14 is the first of two chapters in this book that deal directly with the audiologist's treatment of hearing loss. The diagnostic evaluations performed by audiologists are designed to afford insight into the etiology of a given hearing loss as well as the consequences of hearing loss on patients' interactions with family and the educational, vocational, and social aspects of life. When a hearing loss is identified that cannot be corrected using medicine or surgery, it becomes the audiologist's mission to restore auditory function as fully as possible.

Chapter 14 has discussed considerations about the selection and use of a variety of amplification options. Of the four case studies you have been following through this book, we will be looking specifically at the three who might benefit from amplification. Before reading the case study entries below ask yourself which ear(s) you would fit with amplification for these three patients, what style hearing aid(s) would be appropriate for each case, what types of circuit options you might consider, and whether any hearing assistance technologies beyond hearing aids would be appropriate.

Case Study 1: Conductive Hearing Loss

One would hope that the conductive loss this patient experiences could be managed successfully through medical intervention. However, if a significant hearing loss remained following such intervention, the audiologist would need to address the use of amplification with this patient. Air-conduction hearing aids are always superior to bone-conduction hearing aids when their use is possible. However, if the unresolved conductive hearing loss is accompanied by drainage from the ear, or if the pathology is exacerbated when the canal is closed with a hearing aid, special considerations would need to be made. This is unlikely to be the case here since the otologist reported, and your testing confirms, intact tympanic membranes.

Given the mild-to-moderate nature of this loss (see Figure 4.13) it may be possible to proceed with an air-conduction hearing aid using an open fitting. A less sophisticated digital circuit would probably be appropriate as the more advanced circuits are designed to contend with the reduced sound-processing capabilities of cochlear hearing loss, a difficulty this patient does not have. Conductive hearing losses do not cause the same tolerance problems common to sensory/neural hearing losses, frequently resulting in a patient's desire for higher levels of gain and output. If the

canal must remain open, and acoustic feedback cannot be avoided with an open-fit instrument, a bone-conduction hearing aid may be required for this patient. Many patients with a permanent need for bone-conduction amplification report better hearing with an implanted bone-conduction hearing aid. As stated above, given the intact tympanic membranes, these considerations should not be an issue as air-conduction hearing aids should work well.

The use of select **hearing assistance technologies (HAT)** should be discussed with this patient for times when the hearing aids are not worn. In particular, these may include a vibratory alarm clock, TV amplifier, and an amplified smoke alarm. Additional HATs and the use of further management suggestions, which will be discussed in Chapter 15, are typically not as necessary with patients as in this case study, given the degree of loss and the lack of cochlear involvement.

Case Study 2: Sensory/neural Hearing Loss

You may recall that this 76-year-old male patient has a moderate sensory/neural loss similar to that shown in Figure 4.14 with somewhat reduced speech-recognition abilities that were further compromised when tested at conversational intensities (45 dB HL). The improvement at intensities above conversational levels was a first indication that amplification would benefit this patient. While research suggests that a small number of older adults may do better with monaural amplification, the advantages of a bilateral hearing aid fitting are generally great enough so that two hearing aids would be recommended for this gentleman.

The needs of a mild-to-moderate hearing loss can often be met with any style hearing aid. An instrument placed wholly in the ear is generally more readily accepted by many patients in this age range compared to instruments placed behind the ear, unless the benefits of an open-fitting style are directly demonstrated. Because manual dexterity was not found to be a compromising factor, this patient might express a preference for canal-style hearing aids, which should do well. This size hearing aid will allow for an **audiocoil** (aka **telecoil**), which will prevent feedback when using the telephone. Today's digital hearing aids allow for considerable adjustment to tailor the frequency response to the configuration of the hearing loss. The circuit will also provide the compression circuitry requisite for the reduction in the dynamic range expected with a sensory hearing loss.

The sophistication level of the selected circuit will depend on an exploration of this patient's listening needs and communication environments, but may include directional microphones to enhance signal-to-noise ratios. Probe-microphone measures to verify the aids' performance while in the ear are a must to ensure a proper fit, as is a measure to assess perceived benefit derived from amplification. Hearing aid acceptance will be directly dependent upon this patient's motivation to use hearing aids and the audiologist's ability to convey the expected benefits appropriately.

Given that hearing aids cannot fully restore hearing to normal levels, following an initial adjustment with hearing aids the audiologist should explore whether any hearing assistance technologies would be beneficial. While one might expect a significant reduction in difficulties in hearing conversations, as well as the television and the telephone, the devices, that may have been recommended for the patient with conductive loss (Case Study 1), such as an amplified smoke alarm and a vibratory alarm clock, may be beneficial. This patient should be informed of the availability of large-area hearing assistance technologies in locations such as cinemas and theaters as is required

through the Americans with Disabilities Act. Additional management suggestions to further improve communication will be considered when this case study continues at the end of Chapter 15.

Case Study 4: Pediatric Patient

As mentioned at the outset when this case study was introduced in Chapter 2, this 3-year-old girl passed her neonatal screening. As with all screening measures, some with a hearing disorder will pass the screening (false negative) just as some with no disorder will be incorrectly identified (false positive). While it is possible that the hospital's neonatal screening failed to identify this child's hearing loss, it is also possible that the loss was of delayed onset. In either event, we can expect that the revelation of the diagnostic findings in Chapters 8 and 11 may have been devastating to the parents. As presented in Chapter 15, an emotional impact of the audiologist's test findings is frequently present whether working with children or adults but is especially evident when talking with parents.

The counseling skills of audiologists are never so tested as they are when talking with the parents of a newly diagnosed child with a hearing loss. This includes discussions of the loss itself and the rehabilitative measures that will need to be pursued if the child is to reach the highest possible potential. Certainly, the topic of hearing aids will need to be broached as soon as the emotional impact of the news delivered has subsided enough so that information of this nature can be adequately processed. This most probably will not be at the same office visit in which diagnostic findings are presented, although discussion of hearing aids and management in general terms may be touched on briefly.

Given the power levels currently available in ear-level hearing aids, body-level hearing aids are rarely recommended, usually being reserved only for those cases in which delays in neuromuscular development preclude a child from holding his or her head upright. In-the-ear style hearing aids for this young girl would not be appropriate given the degree of loss and the fact that her ears are still growing rapidly, which would require frequent refabrication of the hearing aid shell. The programmability of digital hearing aids will allow for circuit modifications as further details of her hearing levels become available. Research has never definitively revealed an advantage to frequency response shape or gain levels that are different from those that would be prescribed for an adult with a similar degree of hearing loss. However, research has demonstrated that children who are actively acquiring speech and language skills should have a greater signal-to-noise ratio than adults. As such, hearing aids with direct audio input capabilities for the use of a personal FM system would be important for this child.

This child was referred by a speech-language pathologist who would need to ensure the child's enrollment in both individual and group speech and language therapy along with active involvement by the parents. Progress should be closely monitored with an eye toward consideration of cochlear implantation for this child. Additional management considerations will be addressed when we visit this case study for the last time at the end of Chapter 15.

Summary

Devices designed to augment sound transmission to aid human hearing have evolved from simple sound collectors to instruments that employ some of today's most sophisticated miniature electronics. The styles and circuit options available are designed for both the hearing needs and cosmetic concerns of an ever-growing population of persons with hearing loss.

The audiologist's selection of appropriate amplification must always be followed by some means to verify that the performance received closely approximates the performance expected. The electroacoustic parameters of all hearing aids must meet certain standard specifications, and their performance should be monitored to ensure that adherence to standards is maintained.

As discussed further in the next chapter, the recommendation and fitting of appropriately selected hearing instruments is only one step within the complete hearing (re)habilitation services provided to patients. When the audiologist's treatment efforts with patients reveal the need for greater sound augmentation than hearing aids alone can provide, the appropriate recommendation and instruction for assistive listening/alerting devices should be given. To offer less than the full array of options available to those with hearing loss falls short of optimum patient care.

Study Questions

1. List and describe the electroacoustic characteristics of hearing aids.
2. List the basic components of a hearing aid and describe the purposes of each.
3. What are the advantages and disadvantages of the different types of hearing aids?
4. What measurements are made in hearing aid evaluation, verification, and validation? How might these differ between children and adults?
5. Why are speech audiometrics important in hearing aid evaluation?
6. Briefly describe the differences among FM, infrared, and induction-loop assistive devices.
7. List five assistive listening devices (hearing assistance technologies) and describe when each might be used.
8. What is the difference between hybrid (digital/analog) hearing instruments and fully digital hearing instruments?
9. What is the difference between a middle-ear implant and a cochlear implant?
10. Describe the steps you might follow when checking the daily function of a hearing aid.

Suggested Readings

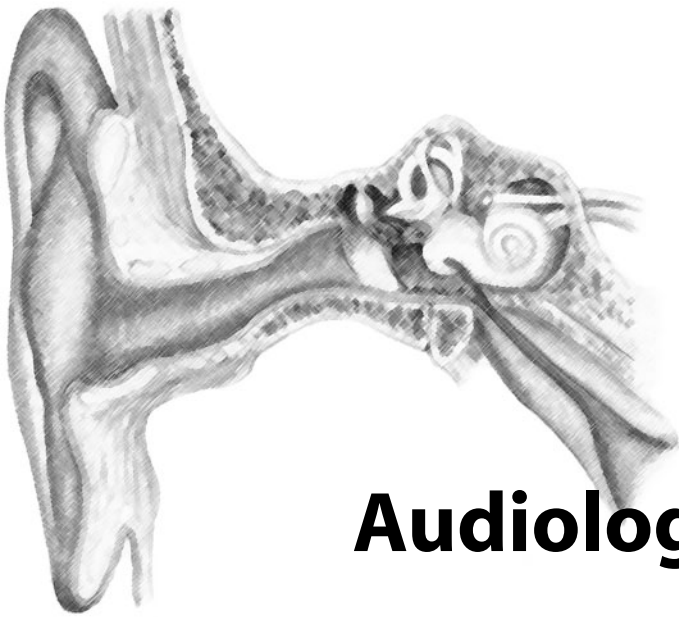
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Audiological Treatment

CLINICAL AUDIOLOGISTS have responsibilities that transcend diagnosis. When a medical condition causes or contributes to a patient's hearing problem, proper otologic consultation must be sought. In the absence of medical treatment, or after its completion, the audiologist is the logical person to take charge of the patient's total audiological management program. If it is decided that hearing aids are indicated for a patient, the audiologist should select and fit the appropriate instruments and provide the needed orientation and follow-up care to ensure optimum efficiency in their use.

The American Speech-Language-Hearing Association scope of practice has long recognized that both speech-language pathologists and audiologists provide aural rehabilitation to children and adults. Frequently, especially with children, rehabilitation efforts will achieve their highest levels of success when audiologists and speech-language pathologists work in concert for the communication enhancement of those with hearing loss.

All preceding materials in this book have led to what must be summarized briefly in the following pages. An understanding of normal and abnormal auditory functioning, together with diagnostic procedures, is without merit unless it culminates in activities that improve the lives of persons with hearing impairment.

LEARNING OBJECTIVES

This chapter is designed to introduce the reader to various aspects of patient management such as taking histories, counseling, writing reports, cooperating with other professionals, and providing audiological treatment. Less emphasis is placed on precise methodologies here than in previous chapters; the intention is to give the reader a brief overview of a number of different aspects of audiology not

previously detailed in this book. Upon completion of this chapter the reader should be able to

- Obtain a proper case history, attending to both the possible pathology underpinnings of hearing loss and the communication impact of the loss.
- Determine when referral to other specialists is necessary to ensure proper hearing loss management.
- Recognize the different styles reports may take to adequately address the concerns pertinent to a variety of professionals who may work with a patient who has hearing loss.
- Recognize some of the factors that can impact, positively and negatively, the counseling given to patients and their families.
- Discuss the principles of hearing-loss management for both children and adults.
- Describe educational options for children with hearing loss.
- Demonstrate an understanding of multicultural issues and their impact on patient care.

Patient Histories

Proper documentation of a patient's history may be as important as the audiometric examination. The manner in which the history is recorded may follow one of several formats, ranging from informality to close adherence to a printed form. Some audiologists prefer to ask only questions that appear to relate to the patient's particular complaints and jot their remarks down informally. This approach requires much skill and experience and allows for possible omission of essential questions.

Some history forms are lengthy and contain more items than are essential for gathering data pertinent to a particular hearing problem. Short forms like those in Figures 15.1 and 15.2 have proven useful in the majority of cases. Although in some busy audiology centers case histories are recorded by ancillary personnel (technicians or clerks) or are mailed to patients for completion before evaluation, it is best for the audiologist to ask the questions or at least to review the questionnaire with the respondent or caregiver.

Any case history form must provide space for a statement of the problem, including why the services of the audiologist were sought. It is helpful to know the patient's own attitude about the appointment. Knowing the reason for the visit to the clinic can provide powerful insights before the rest of the history has been completed or the first test has been administered. Information about the duration and degree of hearing loss should be gleaned, along with family history of ear disease or hearing impairment, noise exposure, or trauma to the ear or head. Reports of vertigo, tinnitus, past surgery related to the ear, previous hearing tests, and so on are most important. History of experience with hearing aids is valuable. Developmental histories of children should be obtained along with any childhood illnesses or accidents and any regressions in development associated with them.

The manner in which questions are answered may be revealing. Often a patient or caregiver hesitates in answering some questions, which may suggest that not too much credence should be given to the answers. This hesitancy sometimes reflects disagreement among family members. However, the fact that questions are answered rapidly, and with apparent self-assurance, does not, in itself, ensure validity. People who have repeatedly answered the same types of questions, perhaps posed by different specialists, become practiced at responding and may find themselves answering

PEDIATRIC CASE HISTORY

File # _____ Date: _____
 Last Name _____ First Name _____ Date of Birth _____
 Sex ()M ()F Parent / Guardian _____

How did you hear of us? _____

GENERAL MEDICAL INFORMATION

What is the name of your child's pediatrician? _____
 Were there any pregnancy complications (illness, accident, medications)? _____

 Were there any birth complications (Low birth weight, jaundice, anoxia, other) ? _____

 Has your child had a vision evaluation? (and where) _____
 Has your child had any serious illness (Mumps, rubella, cytomegalovirus, other)? _____
 Is there a history of ear infection? _____
 Has your child had ear surgery or injury to the ear ? _____
 Does your child have any allergies? _____
 Is your child currently taking any medications? _____
 Other relevant medical information: _____

HEARING LOSS AND DEVELOPMENTAL INFORMATION

Is there a previously documented hearing loss (where tested and what age)? _____

 Is there a family history of childhood hearing loss? _____
 Is your child aware of environmental sounds and other's speech? _____
 Is your child's speech and language age appropriate? _____
 Is your child currently in speech therapy (and where) ? _____
 Is your child's motor development age appropriate? _____
 Does your child have any known behavioral disorders or coexisting handicaps ? _____

OTHER INFORMATION

What is the sex and ages of siblings? _____
 What is your child's school, grade, and teacher? _____
 How would you rate performance in school? _____
 Does your child currently wear hearing aids? _____
 How does your child generally communicate (sign language, speech, gestures)? _____

RELEASE OF INFORMATION

I give permission for release of reports, test results, and recommendations to or from the pediatrician, the referral source, or others as specified.

 Signature (Relation to child)

 Date

FIGURE 15.1 Sample of a form for recording a pediatric history of hearing loss and related conditions.

ADULT CASE HISTORY																	
Last Name: _____ First: _____	File No. _____ Date: _____ Sex ()M ()F Date of Birth _____																
How did you hear of us? _____																	
GENERAL MEDICAL INFORMATION																	
Who is your primary care physician? _____ Do you take any of the following types of medication (circle)? : blood pressure / heart disease / arthritis / daily aspirin / blood thinning / other _____ Do you have any vision disorders? _____ Do you have a chronic or serious illness? _____ Do you have any allergies? _____ Other relevant medical information: _____																	
HEARING HISTORY																	
Y N Do you have a known hearing loss? (Rt ear) (Lt ear) (Both) _____ Y N Is your hearing loss stable? _____ Y N Is there a family history of hearing loss? _____ Y N Have you had a previous hearing evaluation and where? _____ Y N Do you now, or have you ever, worn hearing aids? _____ Y N Do you have noises in your ears (Rt ear) (Lt ear) (Both)? _____ Y N Do you have vertigo or dizziness? _____ Y N Have you <u>ever</u> had recreational, military, or employment noise exposure? _____ Y N Do you have pain, discomfort, or drainage in the ear? _____ Y N Do you have a history of ear infection? _____ Y N Have you had ear surgery? _____ Y N Have you had an injury to your ears? _____ Other _____																	
LISTENING SITUATIONS																	
Please rank the top 4 listening situations in which it is important for you to hear well: <table style="width: 100%; margin-top: 10px;"> <tr> <td>___ conversation with 1 person</td> <td>___ telephone</td> <td>___ television</td> <td>___ in the car</td> </tr> <tr> <td>___ in small groups</td> <td>___ in large groups</td> <td>___ restaurants</td> <td>___ movie / theatre</td> </tr> <tr> <td>___ at religious services</td> <td>___ in meetings</td> <td>___ work places</td> <td>___ outdoors</td> </tr> <tr> <td>___ listening to music</td> <td></td> <td></td> <td></td> </tr> </table>		___ conversation with 1 person	___ telephone	___ television	___ in the car	___ in small groups	___ in large groups	___ restaurants	___ movie / theatre	___ at religious services	___ in meetings	___ work places	___ outdoors	___ listening to music			
___ conversation with 1 person	___ telephone	___ television	___ in the car														
___ in small groups	___ in large groups	___ restaurants	___ movie / theatre														
___ at religious services	___ in meetings	___ work places	___ outdoors														
___ listening to music																	
RELEASE OF INFORMATION																	
I give permission for release of reports, test results, and recommendations to or from my family physician, the referral source, or others as specified. <table style="width: 100%; margin-top: 20px;"> <tr> <td style="width: 50%; border-top: 1px solid black; padding-top: 5px;">Signature</td> <td style="width: 50%; border-top: 1px solid black; padding-top: 5px;">Date</td> </tr> </table>		Signature	Date														
Signature	Date																

FIGURE 15.2 Sample of a form for recording an adult history of hearing loss and related conditions.

questions incorrectly with aplomb. The clinician should try to elicit objective responses as much as possible. Statements of a diagnostic nature, such as “I have Ménière’s disease,” or “My child has a conductive hearing loss,” should be investigated thoroughly, because they may represent the respondent’s incorrect reflection of a previous diagnosis.

A variety of questionnaires exist to provide information on patients’ own perceptions of the impact of their hearing loss within various areas of their lives (Alpiner & McCarthy, 2000; Geier, 1997). These questionnaires frequently have companion forms for the spouse or significant other to complete so that comparisons of perceptions are revealed. These self-assessment measures can be an invaluable adjunct to case histories, serving to clarify the impact of a given hearing loss and aiding in the subsequent recommendations for audiological treatment.

1. An interview with a patient or child’s caregiver should obtain a _____ as perceived by those seeking the audiologist’s care and advice.

Referral to Other Specialists

Audiologists may refer their patients to other specialists for a variety of reasons. They may feel that additional help is needed for either diagnosis or treatment and require the talents of such professionals as otologists, speech-language pathologists, psychologists, genetic counselors, or educators. When referring, a proper report should be sent to provide as much pertinent information as possible. In accordance with the Health Insurance Portability and Accountability Act (HIPAA) (1996), it is mandatory that the patient or guardian signs a release form authorizing the audiologist to provide such information to interested parties. The form, properly filed, may prevent possible legal difficulties.

An audiogram or other data obtained on hearing tests should not be forwarded without qualifying remarks. The audiologist should not suppose that the recipient of test results would totally understand and interpret them correctly. At the other extreme, the audiologist should not include long, verbose reports conveying details of each and every test. Professional time is valuable and should not be occupied in reading unnecessary verbiage. In fact, it is probable that long reports are either not read at all or are only scanned for the pertinent facts.

Each report must be written specifically for the type of specialist to whom it is sent. Audiologists should realize that reports sent about the same patient to an otologist and to a speech-language pathologist might differ greatly in the type of information included and in the manner in which statements are made. In addition, two otologists may differ in the type of information or degree of interpretation they desire. As audiologists get to know particular referral sources, they develop an awareness of how reports should be written for each one. Some may require very formal documents, whereas others will prefer informal synopses. A commonly used format for report writing provides an easy outline for comprehensive reports as well as more cursory notes (Table 15.1).

TABLE 15.1 The SOAP Format for Report Writing

-
- S** – Subjective: Relevant complaints/Reason for visit; subjective observations and family, medical and otologic history
 - O** – Objective: Tests or procedures completed; findings and test conditions
 - A** – Assessment: A summary of the “S” and “O” to provide a diagnostic statement and the implications of the findings
 - P** – Plan: Appropriate recommendations; follow-up
-

1. statement of the problem

Briefly, the organization of a report sent to a professional person might be as follows:

- *First paragraph:* Identification of the patient (name, age, sex, short statement of history); the reason for referral.
- *Second paragraph:* Statement of the type and degree of hearing loss; reference to results that require special attention from the audiometric worksheets and tympanograms; interpretation of test results where needed; implications for communication difficulties.
- *Third paragraph:* Specific treatment plans or recommendations, such as hearing aids; speech, language, or hearing therapy; return for follow-up; avoidance of noise exposure; and so on.

2. When sending reports, HIPAA mandates that a _____ be on file.

Audiology clinics and audiologists are often judged by the reports they send to other professional workers. Messy forms and poorly written or carelessly proofread reports may cause the recipient to deduce that the audiological examination was also poorly done. Reports should be sent as quickly as possible after evaluations. Audiologists represent their clinics and their profession, and good public relations may be as important to the proper management of the patient as good and accurate testing, for one reflects the other.

A student tutorial on basic audiological report writing may be found online at <http://homepages.uc.edu/csd/students/bradhurst>.

Clinical Commentary

Reports to speech-language pathologists should include information on the limitations to speech understanding presented by hearing loss. Familiarity with hearing-test procedures discussed in Chapters 4 and 5 can be invaluable to the speech-language pathologist who works with patients who have hearing loss. Speech-language pathologists should develop a close working relationship with audiologists in their community to facilitate dialogue on behalf of their patients.

Liaisons with Otolaryngologists

It is obvious that the audiologist is not the person to recommend or perform surgery or medical treatment. This is the duty of the physician, preferably an otologist in the case of ear disease. However, most otologists are neither trained nor interested in the intricacies of diagnostic audiology or the nonmedical aspects of audiological treatment. Many cases of hearing loss have no medical underpinnings, thereby obviating medical intervention. In other important, difficult, or contradictory cases, however, consultation between the otologist and the audiologist is of great advantage to the patient. It is a mistake to think of the relationship between audiology and otology as one in which the audiologist merely provides audiometric services for the use of the physician in a diagnosis. In such situations, the role of the audiologist may deteriorate to that of technician. The association between medicine and audiology should be a symbiotic one, a professional relationship that leads to improved patient management.

In referring patients to a physician, audiologists should state in their reports the areas of concern and the reasons for referral. Recommendations for specific treatment should, of course,

not be made. If the patient has a disorder that appears partially or fully reversible (e.g., containing a conductive component caused by otitis media), the audiologist should reschedule the patient for testing following medical attention to ascertain the degree of hearing improvement derived. After an air-bone gap is closed, the sensory/neural portion of a mixed loss may appear different from the pretreatment bone-conduction audiogram. A reevaluation of audiological treatment needs may be required in such cases.

Liaisons with Clinical Psychologists

Sometimes psychological consultation is required because the patient’s problem is, at least partially, complicated by an emotional disorder. The training of most audiologists provides a sufficient vocabulary of psychological terms and association with psychological tests to permit interpretation of a psychologist’s report. As in referrals to physicians, when referring a patient to a psychologist, audiologists should state their particular concerns about the patient and their reasons for referral. In addition to assistance with emotional disorders, the psychologist can provide information about the patient’s performance versus potential—for example, whether a child is reaching academic capabilities or needs some special help. At times, it is not until after consultation that it is decided whether the audiologist or the psychologist will become the central figure in the rehabilitation of the patient.

3. Referral reports to professional colleagues should state _____.

Liaisons with Genetic Counselors

One aspect of audiologist–caregiver interaction that must not be overlooked is the possible need for genetic counseling. Smith (1994) points out that this counseling should not merely provide medical and genetic information, but should also provide support for family members as they learn to deal with their child’s hearing loss. The need to direct families to genetic counselors may be more than ethical, because failure to make such recommendations, when they are indicated, may place the clinician in legal jeopardy.

4. True/False
While there may be ethical reasons to ensure a genetic counseling referral, there are no legal implications to this decision.

According to Smith (1994), families seek genetic counseling for a variety of reasons once they realize that such services are available. They may be interested in the etiology or prognosis of their own or their children’s hearing loss, or they may wish to learn the probability that a later child will have a similar condition. In some cases, if the parents have impaired hearing, they may look at the probability of having an offspring with a hearing loss as a positive outcome.

The year 2003 brought the first use of embryonic genetic screenings for deafness (Robeznieks, 2003). As discussed later in this chapter, a full culture has evolved among the deaf, which embraces its own language and beliefs. This minority group has for years seen its numbers decrease. First, its future members were mainstreamed into public schools and away from the schools for the deaf in which its culture is primarily transmitted, then numbers have further eroded as cochlear implantation has become an increasingly common treatment for pediatric deafness. The use of genetic technologies for the potential business of “designing babies” is seen by some as one more threat to those who live within the Deaf culture.

It is not for the audiologist to judge what decisions should be made on the basis of genetic counseling or upon the findings of embryonic genetic screenings. Rather, it is the audiologist’s responsibility to ensure that families are aware of available genetic counseling services and to know the team to whom referrals should be made. Such a team usually includes a geneticist (a medical doctor), a genetics counselor (usually holding a master’s or doctoral degree), and others as needed.

Liaisons with Speech-Language Pathologists

Although many audiologists have reasonably good academic backgrounds in speech-language pathology, most have limited clinical experience. Historically, the similarities in the backgrounds and early training of audiologists and speech-language pathologists have been parallel, and so audiologists probably identify more closely with speech-language pathologists than with other specialists.

Often an audiologist will see patients because the speech-language pathologist wishes to know if some aspect of a communication disorder is related to a hearing problem, as well as the extent of this relationship. In the case of young, language-delayed children, the identification of a hearing disorder may play a large role in (re)habilitation. In such cases, collaboration between specialists can result in the proper planning of remediation. Some voice or articulation disorders are directly related to the inability to discriminate sounds or to hear in some frequency ranges.

Reports sent from audiologists to speech-language pathologists should be frank and direct. Audiologists should state their opinions regarding the type and extent of hearing impairment, and they should recommend referral to other specialists, such as otolaryngologists or psychologists, if indicated. The audiologist may state an opinion regarding the effects of hearing loss on a patient's speech, but should refrain from specific recommendations regarding therapy.

In working with some pediatric patients, an audiologist may have little more than a clinical hunch about the child's hearing. Phrases such as "hearing is adequate for speech" appear frequently in reports. In such cases, strong recommendations should be made so that follow-up testing is conducted at intervals until bilateral hearing sensitivity can be ascertained. Honest errors made by audiologists may not be caught until valuable time has been lost unless there is routine follow-up.

Liaisons with Teachers of Children with Hearing Impairments

Reports sent to teachers of children with hearing impairment are, in many respects, the same as those sent to speech-language pathologists. Events and developments of recent years have brought clinical audiologists and teachers closer together for the betterment of children with hearing disorders, largely because of the trend toward removing children from the self-contained environment of traditional schools for the deaf into the mainstream of education.

To permit children with hearing loss to compete with their hearing contemporaries, the combined efforts of the two specialties of clinical audiology and education of the deaf have come into closer harmony than ever before. This is largely true because of the emphasis now being placed by many educators on the use of residual hearing. As the barriers between the two groups break down, their formal educations include more overlapping coursework. The harmony achieved can result in teamwork, with the children being the ultimate beneficiaries.

Teachers must learn to understand the implications of audiological management, and audiologists must learn to comprehend the difficulties in the day-to-day management of children in the classroom, especially when those children have impaired hearing. Items of mutual concern include hearing aids, classroom amplification systems, and implications of classroom acoustics. Audiologists' isolation from teachers of children with hearing impairment, and these teachers' reluctance to accept audiological involvement, will disappear as the interactions between these professions continue to increase.

5. True/False
Through a greater understanding of each others' professions audiologists and teachers can work for the betterment of children with hearing loss.

Liaisons with Regular School Classroom Teachers

With the advent of Public Law 94-142, the Education for All Handicapped Children Act of 1975, teachers are educating many children with hearing loss within regular classrooms with no formal preparation in the impact of, and remediation for, hearing impairment. The role of audiology in the delivery of appropriate education for these children, who were mainstreamed into the regular classroom, was a primary impetus for the development of educational audiology as a specialty area within audiology studies (Blair, 1996; Johnson & Benson, 2000).

Educational audiology is still an underrepresented segment of the profession. Regular classroom teachers must usually rely on the information provided by the clinical audiologist in their efforts to meet the educational needs of mainstreamed children with hearing loss. When possible, direct consultation with a child's classroom teacher will go a long way toward helping the teacher and the school address the hearing difficulties a child must endure, even following procurement of appropriate amplification. Reports and/or consultations should go beyond simple documentation of the hearing loss and amplification recommendations and must include specific implications of the hearing loss in concrete and functional terms. These may include such factors as the impact of background classroom noise, resultant fatigue from attempts at visual compensation for the hearing loss, and what high-frequency consonant sounds may still be missed even with amplification (Martin & Clark, 1996). Specific classroom-management suggestions for children with hearing loss (Clark & English, 2004) are welcome additions to any communication with the regular classroom teacher.

Clinical Commentary

Of all the professions, it is the speech-language pathologist with whom the audiologist may collaborate most frequently when working with children. Given the high number of children with reduced hearing and the general paucity of audiologists employed within educational settings, it is apparent that speech-language pathologists play an integral role in the treatment of and advocacy for children with hearing loss. When a school-age child has been identified as having a hearing loss, the speech-language pathologist may be the only person available to provide the in-service training educators may need. This is not to suggest that audiologists are relieved of their advocacy role for children with hearing loss. No child can have too many advocates for justifiable needs. However, the speech-language pathologist's proximity may consign much of the advocacy responsibility to this professional's shoulders.

For handouts useful to classroom teachers who are working with children who have hearing loss, see the Professional Resources section of the Companion Website.



Audiological Counseling

For many clinicians in all areas of human healthcare the word *counseling* means telling patients what is wrong and what must be done about it. Counseling by audiologists must include much more. Audiological counseling is based on the "well-patient model" because the majority of those seen by audiologists are psychologically normal individuals who are trying to cope with the disruption a hearing loss has caused in their lives (Clark, 1994). Those occasional patients who face much deeper psychological difficulty may necessitate referral to mental-health professionals.

The word *care* is one of the primary definitions of counseling, which is usually defined by healthcare providers as a system of information transfer; that is, the counselor (audiologist, physician, hearing aid dispenser) provides directions that the client is expected to follow. This is no surprise since the word *client* comes from the Latin *cliens*, a follower, or one who bows or leans on another (as one's master) for protection. The alternative word *patient*, which is the one used in this book, is not much better since its root is in the Latin *patiens*, to suffer, that is, a person passively receiving care. It is little wonder then that the clinician may expect to operate from the position of power, and the patient from one of subservience. Relationships between patients and their clinicians often come down to the exertion of control (Cassell, 1989), with the clinician exerting authority for what is believed to be in the best interest of the patient. Older, less-educated patients seem to accept a more passive role than their younger, better-educated counterparts (Haug & Lavin, 1983). However, the goal of the audiologist should be to help those they serve to achieve independence and to learn how to solve the problems associated with hearing loss, and the voice of clinical authority must often take a back seat.

6. Informational counseling is not just for patients and their families but should also include the _____ who may not fully recognize the impact of diminished hearing.

Often elderly patients with hearing impairment are not referred to audiologists by other healthcare providers. It is not clear why this is the case, but it may be reasonable to assume that physicians simply expect hearing loss in some patients as a normal consequence of aging, do not realize the extent to which many patients can be helped by counseling and amplification, or do not understand that the impact of the hearing loss is not fully evidenced in a quiet healthcare provider's office. In these matters the audiologist must educate not only the patient and the patient's family, but the medical community as well.

Diagnostic Counseling

It has long been believed that one of the greatest responsibilities of the audiologist is to ensure that test results and diagnostic impressions are imparted adequately to patients and their families. Accurate test results are of paramount importance, but the tests serve merely as instruments to help clinicians give advice and counsel to patients and their families.

To a large degree, the specific approach used and the details included in counseling a patient or family are determined by the audiologist's experience. In the important area of content counseling, it is helpful if the type and degree of loss are explained, and the adult patient, or caregivers of the pediatric patient, acquires a basic understanding of the audiogram. Results of speech audiometry and other diagnostic tests are often not well understood, but if some interest is shown in these tests, the results should be explained in as much detail as the patient desires, using the clearest terms possible with conscious avoidance of audiological jargon. What is surprising to many is that, initially, many people do not appear to show great interest in test results and want to go directly to the "bottom line," with questions about the need for hearing aids, progression of the loss, implications of the loss on general health, and so on. A sensible approach, after testing is completed, is simply to ask what information is desired. If the patient or parent is not prepared to listen, there is not much sense in pouring forth technical information. The counseling role of the audiologist cannot be overstressed, for there is evidence that much of what is explained by clinicians is not accurately retained, even by educated and intelligent persons (Martin, Krueger, & Bernstein, 1990).

In some cases it is necessary to avoid more than a perfunctory explanation of test results, for example, if there is a potentially serious medical condition. On the one hand, an audiologist must not engage in discussions with patients of acoustic tumors and the like; this is the responsibility of the physician. On the other hand, if an audiologist suspects a condition for which a

referral is made to an otologist, the patient will surely want to know the reason for the referral, and tact, diplomacy, and counseling skills are often tested under such conditions.

When discussing test results, the audiologist must create an atmosphere of calm professionalism, for this is often the basis for patient or caregiver confidence in the clinician. Confidence is not determined by whether the audiologist wears a white coat or shows other outward postures of competence. Ordinarily, clinicians should not be separated from their patients by artificial barriers such as desks and tables. As the physical space between parties is decreased, the opportunities for trust and openness increase. After an explanation of test results has been made, the audiologist should solicit questions from the patient and try to answer them in appropriate detail.

Precisely how to convey to parents or caregivers the nature and extent of their children's hearing loss is not universally agreed upon. Many clinicians use a system of direct information transfer. That is, they present information, insofar as it is known, about a child's hearing loss. Often this includes descriptions of the audiogram, definitions of terms, and options for meeting the child's needs. The intent is to educate the caregivers to the point that they can best handle the child's hearing problems. Clinicians often do not realize that their choice of language, verbal and nonverbal, and even the amount of information provided, may have profound effects, both positive and negative, on the receiver of that information. Care should be taken not to present more information than can be taken in. On the initial confirmation of hearing loss, emotions can be quite raw, often making the cognitive processing of new information limited at best. The wise clinician will pace the delivery of information, possibly withholding details until a subsequent visit, while always questioning the recipient to assess comprehension and emotional reaction to the news being given.

It is natural for clinicians to present diagnostic information to the adults who have accompanied a child to the hearing evaluation. Certainly, when children are young and profoundly hearing impaired, it is their caregivers who must decide how the children are to be educated and what amplification alternatives will be considered. However, when children are old enough and have sufficient communication skills, they should be a part of the discussion. This serves to eliminate the resentment that many children feel when they have been excluded from discussions that relate directly to them. Naturally, when children are very young, severely hearing impaired, or with multiple handicaps, it is the adults who should be addressed, but always be attentive to the child's feelings.

Elderly people, as well as teenagers, resent being ignored or discussed as if they were not there. When discussions about the person with the hearing loss are directed solely to others in attendance, that person rapidly begins to feel of marginal importance to the rehabilitative process. Assistive listening devices can be very useful in helping patients through the counseling process if they do not have their own hearing instruments (Chapter 13).

7. True/False

All test results should be given in full detail, albeit free of professional jargon, immediately following an examination.

Emotional Response to Hearing Loss

Parents are often confused and disturbed by new and unusual terminology, and as such even the very words used to describe the child's problems may be critical (Martin, 1994). Martin, George, O'Neal, and Daly (1987) conducted a survey in the United States and learned that parents (or other caregivers) are often not receptive to detailed information immediately after they have learned that their child has an irreversible hearing loss. Respondents to this survey indicated that initial parental reactions include sorrow, shock, denial, fear, anger, helplessness, and blame, although not all of these reactions will necessarily appear and may show up in any order. It takes varying and sometimes prolonged amounts of time for the diagnosis of hearing loss to be accepted. Acceptance of this diagnosis is often easier for parents and others

8. True/False

Upon receipt of diagnostic information about their own hearing loss, adults do not experience the same types of emotional turmoil as do parents of young children with hearing loss.

if they have the opportunity to observe hearing tests as they are performed on their children. By the time an adult patient reaches the audiologist, a greater level of acceptance has often been attained. Yet, it is still important that audiologists remain cognizant of the impact their words may carry when relaying diagnostic findings to adults.

The reactions of parents to the realization that their child has a hearing impairment are not always the same. Whether externalized or internalized, it is safe to say that the effect is generally quite intense. As Moses (1979) points out, parents view their children as extensions of themselves, with hopes and dreams of perfection. When an imperfection is uncovered, the dreams become shattered. Because of its “invisibility,” hearing impairment often does not appear to be a true disability, which makes the adjustment even more difficult for the parents.

Many people have inferred that adults with acquired hearing loss do not suffer significant shock, disappointment, anger, sadness, or other emotions because they more or less expect the diagnosis they hear. Apparently, however, this is far from true in many cases, and adults may be much more emotionally fragile than had been supposed (Glass & Elliot, 1992; Martin, Krall, & O’Neal, 1989). Assessing the emotional reaction of a patient to the news of a hearing loss often cannot be gauged accurately on the basis of a patient’s affect, even by the most sensitive clinician (Martin, Barr, & Bernstein, 1992). As with parents, it is often difficult to distinguish those adults who receive what they perceive to be bad news about irreversible hearing loss in a matter-of-fact way from those for whom the same news is catastrophic.

It is almost always desirable to ask new adult patients to be accompanied to their hearing evaluations by someone significant to them, such as a spouse. The support afforded and the clinical insights gained through such a practice can be immeasurable, yet the involvement of a third party is most often not encouraged as it should be (Stika, Ross, & Cuevas, 2002). When working with children, both parents should be present at the evaluation whenever possible. Observing the tests, as well as the responses given, allows these individuals insights into the nature of the hearing disability that are difficult to comprehend when only explained.

Following the pronouncement that a hearing loss is probably irreversible, the emotional states of parents or adult patients may make it difficult for them to understand and process subsequently presented technical aspects of their hearing disorder and explanations of test results. At the same time, patients complain that they want to have much more information at the time of diagnosis than audiologists, physicians, and hearing aid dispensers usually provide (Martin et al., 1989). A major complaint by those seeking audiological care is that they feel rushed while in the clinician’s office. As stated earlier, one solution to this problem is to ask patients or parents what they know about their problems and what they wish to be told. It should be emphasized that further counseling is available, and patients should be encouraged to call for more in-depth discussion of their hearing problems. After people have had a chance to compose themselves, they often think of many pertinent questions or details that they want explained. Opportunities for further consultation with the clinician should be provided at the earliest possible time. Audiological counseling should be viewed as a continuing process, and patients and families should feel that they can come to their audiologist/counselor when they need assistance.

Van Hecke (1994) reviewed the states through which many people pass when hearing loss is diagnosed. Parents often go through a period of *denial* as a means of self-defense against what they perceive to be very bad news. The frequently cited seven-year delay between the time adults first suspect that their own hearing has decreased and the time in which assistance is sought speaks volumes on the strength of denial among adults with hearing loss. Often by the time adults get to an audiologist, they have largely worked through their denial. During a state of denial, it is frequently fruitless even to try to provide details of the diagnosis and recommendations for treatment, as patients are simply incapable of acceptance at this juncture.

Faced with denial, the audiologist might state, “The idea that your child may have a hearing loss seems difficult for you to accept. Can you tell me what it would mean to you if my

diagnosis is correct?” Acknowledging difficulty in accepting the test findings can open a dialogue that may be helpful in moving beyond this aspect of the grieving process. The same approach can be useful when working with adult patients who have not fully reconciled themselves to a newly emerging self-concept as one with hearing loss.

As mourning over the loss of the perfect child continues, parents frequently express *anger* as they relinquish their feelings of denial. This anger may be transferred to loved ones, marital partners, audiologists, physicians, or God, leaving virtually no one invulnerable. Adult patients may also be angry at society's lack of understanding of the difficulties they encounter. Unintentionally hurtful statements such as, “He only hears when he wants to hear,” only fuel these feelings. Audiologists must be able to function as counselors and accept expressed anger, even if it is directed toward them. Objectivity at this point is crucial.

While traversing through the maze of emotions, parents frequently will go through a period of *guilt*. Parents who persist in seeking explanations for the cause of the hearing loss may be looking for a way out of the awful sense that they have somehow done this to their child or are being punished for some past sin. If the guilt is projected toward the other marital partner, the marriage can become shaky; divorce is not uncommon among parents of children with disabilities. Indeed, many parents never pass from the guilt state, with unfortunate consequences for children who may become spoiled or overprotected or may never reach their full potential. Merely telling parents that they need not blame themselves is often fruitless, but the audiologist should try to avoid words or actions that promote guilt. Adult patients, too, may feel guilt over their hearing loss, especially if, as in noise-induced hearing loss, they believe that preventive measures that had been ignored could have circumvented the disorder.

As parents cease reeling from the impact of the “bad news” about their child, they seek ways to maximize the child's potential. Unfortunately, they may become so overloaded with assignments, information, and advice (albeit well meaning) from professionals, family, and friends, that they believe they are inadequate for the job at hand. Subsequently, anxiety may increase, which must be dealt with before any form of intervention can become effective for the child. Audiologists must be careful not to overwhelm adults as well. The presentation of too many management options can create confusion and a patient who opts to postpone the purchase of hearing aids and the embarkation of further audiological treatment. What are often presented as “stages” of grief rarely appear in a set order, and persons who seemingly have traversed through a variety of stages can backslide and revisit portions of their grief at later dates.

When presenting diagnostic information that may be painful, audiologists must temper their enthusiasm for launching (re)habilitative efforts with patience and understanding. Reliance on feedback from parents, or adult patients, regarding their anxiety levels during counseling may be misleading. For example, what appears to be a lax or indifferent attitude may be a smokescreen for fear and bewilderment.

Clinical Commentary

Speech-language pathologists and audiologists, like healthcare professionals in other disciplines, frequently must break bad news to those they serve. As discussed by Clark and English (2004), at these times clinicians must encourage clients to express their feelings and be prepared to respond with empathy and warmth toward whatever surfaces. Adequate time must be given for both the delivery and receipt of bad news as well as sufficient temporal space to “regroup” as needed before moving forward into rehabilitation.

9. Emotional responses to bad news may include _____, _____, and _____ (among others) but may not occur in a set order and may reappear at later dates.

Personal Adjustment Counseling

Expanding counseling beyond the mere transfer of information reflects a reconsideration of the counseling roles of audiologists that has been evident in recent years. Counseling should have a supportive base, which helps patients and families to make practical changes in their lives, which, in turn, will help them to develop a more positive approach to their own disabilities, the technological assistance available to them, and the residual communication difficulties that, for many, are inevitable (Clark, 1994; Clark & English, 2004).

An understanding of the differences between professional and nonprofessional counselors is paramount to the audiologist. Professional counselors are those who are specifically educated and trained in this area and counseling is the primary service they provide. These professionals include psychologists, social workers, and psychiatrists, although modern psychiatry appears to be turning away from a counseling profession to a neurochemical discipline. Nonprofessional counselors include those others who may or may not lack specific and advanced training in counseling but provide their counseling to directly augment their primary service. These may include audiologists, speech-language pathologists, physicians, educators, clergy, attorneys, friends, and family. Psychotherapy is in the domain of professional counselors. Understanding the differences between psychotherapeutic counseling and personal adjustment counseling allows nonprofessional counselors to feel more comfortable within their counseling role. It is the audiologist's role in supportive personal adjustment counseling that is often slighted in patient care, and it must be cultivated for the patient's benefit. Those who perform any counseling at all must know their strengths and limitations and must recognize the critical impact that their words and deeds can have on patients and their families.

Sometimes caregivers opt for a plan of action that is not what the audiologist believes to be in a particular child's best interest. Because of their background and training, many audiologists believe that the first avenue followed should employ the aural/oral approach, maximizing residual hearing with amplification and encouraging communication through speech. A different decision by a parent may appear to be "wrong" to the clinician. The function of the audiologist should be to convey educational and habilitative options to the parents (Clark, 1983). While these alternatives should be explained carefully, objectively, and without bias, it is the parents who make the final decisions regarding hearing-loss management for their children.

Before parents can help their children, they must be helped themselves. They must be taught to cope with the challenge of parenting a child with a hearing impairment. They must learn to continue to give and to accept love, and to include the entire family in normal activities, as well as in activities prescribed for the child with the hearing loss. The audiologist, as a sensitive and empathetic listener, must learn to see beyond the words to the feelings of family members. Intervention without personal concern may be useless.

Clinical Commentary

One of the greatest impediments to effective patient counseling is a poor match between the feelings underlying parent or adult patient statements and the response given by the audiologist. The parent who states, "Those hearing aids look so big on his tiny ears" is no more commenting on the size of the hearing aids than is the adult who states, "I always thought hearing aids were for old people" is making a comment on hearing loss demographics. Pointing out that hearing aids are much smaller than in the past, or that the audiologist has many patients much younger than the present adult patient, is a clear communication mismatch. A better response in either situation that speaks to the pain underlying the recognized need for hearing aids might be an acknowledgment as simple as, "I'm sure I would find it quite difficult accepting the unexpected and unwanted changes that have come into your life."

It is frequently the unasked questions that audiologists must sense and answer. Patients, and their families, are frequently fearful of inquiring about the possible progression of hearing loss. Many older patients fear that it is only a matter of time before they will lose their hearing entirely. Parents of young children may fear further impact on the rehabilitative goals their children are striving to attain. Although progression of hearing loss may or may not have been demonstrated by repeated hearing evaluations, it is possible for the audiologist to play a calming and reassuring role.

All audiologists have seen patients who, for whatever reason, if given the opportunity would opt to avoid the treatment offered. These may be adult patients who have not fully recognized the impact of their hearing loss or who have not come to grips with the view of themselves as someone who is no longer a fully functioning, unimpaired, adult; teenaged students with hearing loss who shun continued use of the visible electroacoustic accessories others insist they wear; or very elderly patients who may believe they have outlived their usefulness and see no reason to put forth the efforts others are asking of them. Ultimately, patients will act through their own values when making decisions that affect their lives. While it is the audiologist's responsibility to recognize and accept conditions that may affect their patients' decisions, audiologists must also always be prepared to explore with their patients various means that may help them to recognize the value of alternative viewpoints and actions (Clark, 2007).

In the provision of personal adjustment counseling, the audiologist will be well served by remembering three key points. *Reflect* concerns back to the patient. In so doing, the audiologist ensures that concerns were properly understood while simultaneously conveying an empathic desire to see the problem at hand from the patient or parent perspective. Effective reflections come in lead statements such as, "As I understand you, you are saying" or, more simply, "In other words." *Accept* the patients' or parents' expressed feelings or attitudes as valid views or percepts of the situation at the moment. It is when we make judgments on feelings and attitudes that sharing stops and assistance wanes. Only after audiologists do these first two can they truly begin to *explore* different avenues that may open opportunities for the future (Clark, 1999, 2000). What persons with hearing loss, and their families, are asking for is no more than they are entitled to: a concerned and compassionate clinician who is willing to give sufficient time and express appropriate interest in what, to many people, is a profound and disturbing disability. Counseling beyond an information transfer should be an integral component to the services audiologists provide although it is frequently under-delivered. Further discussion of counseling techniques for audiologists may be found in the Suggested Readings list at the end of this chapter.

10. A clear difference in purpose exists between the delivery of psychotherapy by a mental health professional and the delivery of _____ counseling provided by speech-language pathologists and audiologists.

Support Groups

Adult patients and family members of pediatric patients find that support groups are of great assistance in dealing with hearing loss. Participants quickly learn within a group that they are not alone in the difficulties they experience. Support groups addressing the pediatric population may be designed for grandparents or siblings to address their specific issues separate from the traditional parent support groups (Atkins, 1994).

Teens with hearing loss who have been mainstreamed often confront their communication challenges and frustrations unaware that there are others with the same difficulties. Teen support groups not only provide a valuable outlet and learning environment for these children but also allow parents an opportunity to meet again as a group to address the adolescent issues that were not foreseen in their earlier group experiences when their children were much

11. Four areas in which the Americans with Disabilities Act prohibit discrimination against persons with disabilities include _____, _____, _____, and _____.

younger. The consumer support group, the Alexander Graham Bell Association for the Deaf and Hard of Hearing (www.agbell.org), provides online support and regional/state meetings for parents, teens with hearing loss, and others in the family constellation of pediatric hearing loss. For adults with hearing loss, one valuable group with local chapters around the country is the Hearing Loss Association of America (www.hearingloss.org), which publishes its own consumer-oriented journal. Audiologists need to make referrals to support groups to supplement the treatment services they are providing their patients of all ages.

Management of Adult Hearing Impairment

The passage of Public Law 101-336, the Americans with Disabilities Act (1991), prohibits discrimination against persons with disabilities in such areas as transportation, state and local government, public accommodations, employment, and telecommunications. This law sprang from a grassroots movement and has had profound effects for individuals with hearing loss. It should be understood by audiologists, in addition to its technical implications, for in part it helps to reduce the negative images that are associated with physically and mentally challenged individuals, and it brings with it a new sensitivity to the feelings of those with hearing impairment. Audiologists are urged to consider the words they use in case management, for example, substituting *disability* for *handicap*, because a disabled person is only handicapped when faced with an insurmountable barrier. The person, and not the disability, should be emphasized as part of what has been called the “people first” movement; hence, “person with a hearing loss” should replace “hearing-impaired person.”

Adult patients requiring audiological management of their hearing problems are usually adventitiously impaired. Although some of these hearing losses are sudden, for example, as the result of drug therapy or illness, most are gradual, almost insidious. The management of these patients has been termed *aural rehabilitation* and, more recently, **audiological rehabilitation** or *audiological treatment*.

It is important to separate the concepts of **hearing impairment**, an abnormality that is psychological, physiological, or anatomical (defined audiometrically), and **hearing disability**, which relates to an individual’s inability to perform biologically and socially useful functions, from **hearing handicap**, the ways in which individuals are disadvantaged in fulfilling their desired roles (usually defined on self-assessment scales) (World Health Organization, 1980). While these terms are somewhat ingrained within the practice mindset of many health professionals, audiologists should be aware that the World Health Organization (2001) has moved away from terminology that implies a consequence of disease to a “components of health” classification. Within this newer classification framework, *disability* is replaced by *activity limitations* (e.g., effective communication) and *handicap* is replaced by *participation restriction* (e.g., within social, vocational, and educational arenas).

The degree of participation restriction represented by activity limitations presented by a given hearing impairment can be highly individual and must be taken into account in rehabilitative planning. Indeed, participation restrictions will be directly related to the availability of personal amplification, assistive devices, workplace accommodations, societal views toward the disabled, and the presence of legislation such as the **Americans with Disabilities Act**.

When labeling activity limitation based upon a given level of hearing impairment expressed in terms of the pure-tone average (PTA) (Table 4.1), it is important to remember that two- and

three-frequency PTAs were designed to predict the threshold of speech and, as such, often misrepresent the impact of a given hearing loss. Although these averages are often used in assigning hearing-loss labels, the prediction of speech thresholds and the assignment of hearing-loss labels are two quite different processes. Although the variable pure-tone average (VPTA) discussed in Chapter 4 may serve better for the latter, it should be noted that the accuracy of any labeling system in describing a given individual is contingent on a variety of sometimes unknown factors.

Audiological treatment has changed in recent years for several reasons, including technological breakthroughs and cultural influences. Traditional rehabilitative techniques with adults, such as speechreading and auditory training, continue to be practiced, despite the fact that the data do not consistently prove these approaches alone to be effective. However, there is much that can be done to assist patients and their families in addressing the hearing problems that can become so intrusive in their lives.

While medical science has advanced in the treatment of diseases that cause hearing loss, similar advances have served to prolong life, with the result that for the first time in history the population of the United States consists of more older people than younger people. Because hearing loss is one of the almost inevitable results of aging, the number of adults with acquired hearing loss is increasing.

A condition that has been thrust into the public's consciousness in the past several decades is **Alzheimer's disease**¹, which causes confusion, disorientation, and, what is most commonly associated with this condition, memory loss. The disease begins in late middle life, often results in death within 10 to 20 years, and is said to be the largest single cause of **dementia**. The incidence of Alzheimer's appears to be increasing rapidly, in part because its diagnosis has become much easier with the advent of MRI and PET scans.

It is known that the incidence of Alzheimer's disease increases with age and therefore may be a concomitant occurrence with presbycusis, making hearing-instrument use and other avenues of auditory rehabilitation even more difficult. Since memory loss is an unfortunate companion of aging, and both conditions present their own problems with communication, the challenge to the audiologist is significantly increased in those cases where the conditions co-exist (Cacace, 2007). Audiologists must be prepared to meet this challenge.

Before an audiological treatment program can begin, it is essential that the patient's hearing disability be assessed. It has been customary to base this assessment on audiometric data alone. The information provided earlier in this book is essential to patient management, but it does not supersede other information that may also be critical, such as the patient's own view of the disability, individual needs and preferences, socioeconomic status, education, vocation, and a host of other important non-auditory considerations (American Academy of Audiology, 2006).

A number of attempts to assess the degree of activity limitation have been based both on audiometric data and on scales computed with the assistance of the patient. A review and compilation of scales to assess the impact of hearing loss is provided by Alpiner and McCarthy (2000). Although none of these methods is perfect, they assist the audiologist in compiling data about how the hearing impairment affects the central figure in the treatment process. After all, it does little good to insist that a patient needs wearable amplification when the patient minimizes the effects of the hearing loss and has no intention of using hearing aids.

The goal of adult audiological treatment is always to make maximum use of residual hearing. Residual hearing is useful hearing, and it is not always easily discernible by looking at an audiogram, speech-recognition threshold, or word-recognition score. The patient's residual hearing is the difference, in decibels, between the auditory threshold and the uncomfortable

12. The World Health Organization's components of health classification of disease helps audiologists view hearing loss in terms of _____ and _____.

13. Meaningful recommendations for hearing rehabilitation must be based upon the results of the audiological evaluation coupled with information on _____ and _____.

loudness level. The broader this dynamic range of hearing, the better candidate the patient is for hearing aids and audiological rehabilitation.

A number of decisions must be made after the hearing has been assessed. The decision on hearing aids must be made, and proper selection and orientation should be arranged. The nature of the orientation must be selected: that is, whether intervention should be done individually or in groups, who should constitute the specific group, what visual cues should be emphasized, how speech can be conserved, and so on. Treatment efforts must be geared to the individual, whose curiosity and ability to comprehend should not be underestimated. The patient should be educated as fully as possible about hearing loss in general and about the specific disability in particular. How the ear works and what has gone wrong, the effects of the loss on speech communication, implications for progression of the loss, the array of hearing assistance technologies available, and interactions with family and friends must all be discussed openly and honestly with the patient, in the presence of a close friend or family member, whenever possible.

Many audiologists are more comfortable in the role of diagnostician than hearing-loss manager. Modern audiology demands that the clinician be facile in both of these areas; indeed, it is within the latter that audiologists will find the greater autonomy. There is an unfortunate tendency in clinical audiology to provide hearing loss treatment largely, if not often solely, through available technology. To fail to provide direct intervention through training in effective communication is a disservice to the patient and to the profession of audiology (Clark, 2009, 2010; Clark, Kricos, & Sweetow, 2010).

Beyond Hearing Aids and Assistive Devices

A large-scale study of adults with hearing loss and their family members was conducted by the National Council on the Aging (NCOA) (Kochkin & Rogin, 2000). The study documented that untreated hearing loss increases levels of depression, anxiety, anger, and frustration. These findings parallel earlier studies, which have shown a demonstrable increase in functional disability in the elderly for every 10-dB increase in hearing loss (e.g., Bess, Lichtenstein, Logan, Burger, & Nelson, 1989). It is now well documented that the use of hearing aids can improve functional health status in elderly patients with sensory/neural hearing loss due to decreases in the functional, psychosocial, and emotional impacts of reduced communication (Chisolm et al., 2007; Crandell, 1998; Kochkin & Rogin, 2000; Larson et al., 2000) and that the short-term benefits initially reported are sustained into the long term (Bratt, Rosenfeld, & Williams, 2007). In addition, specific communication training has been found to further lessen the negative impacts of hearing loss, and many resources are available that provide useful guidance for audiologists in the provision of both individual and group hearing therapy (e.g., Clark & English, 2004; Wayner & Abrahamson, 1996).

A major task of any dispensing audiologist should be to train the patient with hearing loss in the maximum use of residual hearing. For the greatest effectiveness with hearing aids, this should go beyond the standard mechanics of orientation to the use and care of hearing instruments. In spite of the growing evidence that *auditory training* or, more appropriately with adults, *auditory retraining*, can significantly augment the benefit derived from amplification (Kricos & McCarthy, 2007), this adjunct to the audiologist's services to adults is frequently omitted from the treatment provided. A home-based, interactive, and adaptive computer-based approach to auditory retraining known as LACE (Listening and Communication Enhancement) has been demonstrated to positively impact the communication function of adults (Sweetow & Sabes, 2006) and may prove to be a beneficial adjunct to the general orientation to amplification use the audiologist provides. Not only can auditory retraining improve a patient's communication effectiveness, there is evidence that this improvement can be pharmacologically enhanced (Tobey et al.,

2005). These preliminary results may prove to be of considerable benefit to many who strive to attain the highest levels of communicative function possible.

Auditory retraining with adults has evolved to encompass instruction geared to enhance recognition of and intervention for those variables within the environment, or poor speaker or listener habits that impede successful communication (Clark & English, 2004; Trychin, 1994). Patients should be taught to be more assertive in regard to advising others of their communication needs and to maximize their communicative skills, in part by managing their environments. People should be encouraged to be in the same room with and facing others with whom they speak. Position in the room should be manipulated to take advantage of lighting. Room noise should be minimized during conversation, and hearing assistance technologies should be used when appropriate. The patient's primary communication partners should be actively involved in all training to gain a greater appreciation of realistic communication expectations and to learn ways they can further enhance successful communication. **Hearing therapy**, or communication training, should be integral to a more comprehensive delivery of audiological services and is endorsed by the primary consumer advocacy group for those with hearing loss, the Hearing Loss Association of America, as a recommended adjunct to hearing aid fittings (Self Help for Hard of Hearing People, Inc., 1996). Despite this endorsement, surveys continue to demonstrate that the predominant protocol for hearing aid dispensing has not changed much through the years, with the fitting process reaching completion in most cases within three to five visits (Skaft, 2000).

14. Comprehensive hearing loss treatment for adults should go beyond the fitting of personal amplification and exploration of augmentative assistive listening devices and include _____.

Clinical Commentary

Unfortunately, for most hearing aid users maximum benefit with amplification cannot be approximated, let alone achieved, in the traditional three-to-five-visit dispensing protocol. Until audiologists begin to provide their patients with considerably more than the mechanics of hearing aid use, it can be expected that general satisfaction levels with amplification, while significantly higher than in the past, will not meet the levels that technological advances are capable of providing.

One of the most effective means of providing communication training is through group classes designed for the individual with hearing loss and a spouse, a close family member, or a friend. The value of group intervention transcends any functional improvement in communication that may be attained. Group work with adults has a psychotherapeutic value that cannot be underestimated. Many adults, particularly older people, become depressed over their hearing losses. They may feel persecuted and alone. Although they may realize, on an intellectual level, that their problems are not unique, emotionally they feel isolated. The mere experience of being with people their own age, and with similar problems, may lift their spirits and aid in their rehabilitation. The opportunity for members of the group to share what has worked for them in their attempts to address their communication difficulties is beneficial to all group members. The educational and emotional values of group intervention can only be approximated. However, even with the strongest attempts at intervention, some adult patients with sensory/neural hearing losses cannot make the adjustment to hearing aids or refuse to attempt to do so.

Unfortunately, group communication training, which for many patients learning to adjust to amplification has been essential to success, has yet to be fully embraced by audiologists (Clark, 2001, 2002). Few audiologists provide communication training for adults primarily due to the time investment required for training and the low reimbursement for the provision of these services.

It is a misconception that this is time poorly spent, because the resultant greater acceptance of hearing aids through such services has its own payoff through fewer hearing aid rejections. Not only is group or individual training rarely provided, many adults with hearing loss may not follow through with recommendations for home study such as with the LACE, believing that today's hearing aid circuitry should fully compensate for their problems or that residual difficulties are a limitation with which they must contend. It is imperative that at the very least, audiologists discuss communication strategies for persons with hearing loss and those they live with during the hearing aid fitting process (Clark, 2009; Clark et al., in press).



For printed material, including communication suggestions to supplement the hearing loss consultation, see the Professional Resources Section of the Companion Website.

Speechreading Training with Adults

It is the mistaken concept among many laypersons, and among some professionals as well, that if hearing becomes impaired, it can be replaced by **lipreading**, in which the words of a speaker may be recognized by watching the lips. The term **speechreading** has replaced *lipreading*, because it is recognized that the visual perception of speech requires much more than attending to lip movements alone. Recognition of facial expressions, gestures, body movements, and so on contributes to the perception of speech.

Many speech sounds are produced so that they may be recognized on the lips alone, at least in terms of their general manner and place of production. Some sounds, however, such as /p/, /m/, and /b/, are produced in such a way that they are difficult to differentiate from each other based on visual cues alone. Other sounds, such as /g/, /k/, and /h/, cannot be perceived visually at all.

Although much has been done to investigate the value of speechreading, and numbers of methods are available to teach this skill to people with hearing loss, it is still a considerably misunderstood concept. It is a gross error to believe that speechreading alone can replace hearing in the complete understanding of spoken discourse. It is also an error to believe that more than about 50% of the sounds of speech may be perceived through speechreading alone.

For speechreading to be of maximum value to the patient, it should be taught in conjunction with the coping strategies addressed in communication training so that the combined effects of vision and residual hearing may be gained. When the two senses are used simultaneously, they interact synergistically; the combined effect on speech understanding is greater for watching and listening together than for either watching alone or listening alone.

Many people believe that speechreading is an art that requires an innate talent possessed more by some persons than by others. It is probably true that some people are more visually oriented than others. Some people do better on speechreading tests without training than do other people who have had a number of speechreading lessons. Of course, a speaker's poor speaking habits can contribute to the listener's difficulty in speechreading. Direct intervention in developing clear speaking habits has been found to aid in successful speechreading (Caissie et al., 2005).

The methods of teaching speechreading to adults vary considerably in their philosophy and implementation. Some include an analytic approach to the movements of the speaker's lips, whereas others are more synthetic. Computer-assisted training in speechreading that implements CD technology has been used. It is enough to say in this brief discussion that speechreading should be made as natural to the patient as possible, utilizing residual hearing through hearing aids if this is indicated.

15. Two approaches to speechreading training are _____ and _____.

15. synthetic, analytic

Clinical Commentary

The scopes of practice for both speech-language pathologists and audiologists include provision of services in audiological (re)habilitation for adults and children. As the range of audiological rehabilitation services continues to expand, clearly the roles these two professional groups will bring to service delivery will differ based upon knowledge and skills unique to each profession. Quite frequently, the audiological services provided will be a collaborative effort between speech-language pathologists and audiologists. As stated by the ASHA Board of Ethics, the professional's personal scope of practice in this area will be dictated by his or her own education, training, and experience (ASHA, 2002b).

Management of Childhood Hearing Impairment

Although other conditions may contribute to delay the onset of normal language and speech, often hearing loss is the primary problem. Whether a hearing loss is present at birth or develops at some time afterward can make a profound difference in language acquisition. When it exists before the normal development of language, it is referred to as **prelinguistic hearing loss**. A hearing loss that begins after language concepts are formed is called **postlinguistic hearing loss**. Naturally, the later in life a hearing loss begins, the better the chance to conserve the speech and language that a child has already learned through the hearing sense.

One obligation of the audiologist is to pursue medical reversal of a hearing loss as soon as that possibility presents itself. Determination of otologic or surgical treatment is based on medical decisions. Audiologists should make a medical referral immediately when otitis media or other infections are seen, or when there is any indication of a structural deviation that might involve the auditory system. If medical treatment of a hearing loss is impossible, or still leaves the child with some hearing loss, further audiological intervention is needed, including family counseling.

Auditory Training with Children

There are obvious differences in the approaches to patients with prelinguistic and postlinguistic hearing losses. Children who have suffered hearing loss from birth or early childhood cannot call on the memory of speech sounds, and so must begin training in special ways. **Auditory training** programs for children may be quite comprehensive, and specific goals and objectives should be established based on individual needs. Often these programs will concentrate on auditory skill development in the areas of sound awareness, sound discrimination, sound identification, and sound/speech comprehension through both formal and informal activities. The more readily the hearing aids are accepted, the sooner training can begin (see Figure 15.3).

Speechreading Training with Children

Speechreading for small children should begin early in life. They should be encouraged to watch the faces of their parents and others. Speech to these children should be slow, simple, and carefully articulated, without exaggeration of the movements of the face and mouth. The error committed by many parents is to mouth speech without voice, in the belief that the exaggerations will help the children speechread and that voice is unnecessary since the children are “deaf.” Using voice allows the production of the speech sounds to be more natural and, it is hoped, provides some auditory cues if the children’s residual hearing has been tapped by amplification.



FIGURE 15.3 A major component of any auditory enrichment program is to ensure that a clear signal reaches the ear. Here the teacher's voice is picked up by a head-worn microphone and sent via FM transmission to the receiver attached to the child's hearing aid. (Courtesy of Phonak)

Educational Options

The Bureau of Education of the Handicapped was established in 1966, which in turn led to implementation of Public Law 94-142 in 1975, the Education for All Handicapped Children Law. This law mandates **mainstreaming** children with disabilities whenever possible, their education to be carried out in the "least restrictive environment." For many children with hearing loss, mainstreaming requires that they spend their entire school day in a regular classroom except for times specifically designed to receive support services related to their disability. More than half of the approximately 80,000 children with profound hearing losses in the United States were moved away from specialized schools, many of which began to close as a consequence (Lane, 1987). It is unfortunate that the "least restrictive environment" was interpreted as endorsing mainstreaming for *all* children. Restrictive environments may be more appropriately defined as settings that limit a child's classroom potential, and the least restrictive environment is that environment most appropriate for the child (Ross, Brackett, & Maxon, 1991).

The Education of the Handicapped Act Amendments (P.L. 99-457) was enacted in 1986 to provide guidelines for offering assistance from birth to children with hearing loss and other disabilities. The purpose of this law, in addition to offering assistance and guidance to families with younger children, was to develop family-centered programs. Public Law 94-142 mandated the **individual education plan (IEP)**, and Public Law 99-457 encouraged the **individual family service plan (IFSP)**. The No Child Left Behind (NCLB) Act (2001) mandates high achievement for all students. To meet the spirit of the law for each of these important legislations, audiologists must not only identify, assess, and plan intervention for children with hearing loss but must also be familiar with general education curriculum standards, goals, and benchmarks as well as the supports that children with hearing loss may need to attain their highest levels of achievement. Early intervention services include audiometry, speech-language pathology, case management, family training, health services, nutrition, occupational therapy, physical therapy, psychological and social services, transportation, and more. The Individuals with Disabilities Education Act of

TABLE 15.2 Responsibilities of the Educational Audiologist

(Source: ASHA, 2004b)

-
- Creation and administration of hearing-loss identification programs
 - Evaluation of children with identified hearing loss
 - Appropriate referral for medical and professional attention for further assessment as needed
 - Creation and administration of programs for the prevention of hearing loss
 - Counseling and guidance of children, parents, and teachers regarding hearing loss
 - Determination of need for and selection and fitting of personal and classroom amplification and hearing assistance technologies and determination of the effectiveness of such devices
-

1990 (P.L. 101-476) and the Individuals with Disabilities Education Act Amendments of 1997 (P.L. 105-117) added legal clarification. All this legislation places educational audiology on a firm legal footing, although there is evidence that the enactment of laws does not necessarily translate into actual services for some of the children they are designed to assist (Johnson, 1991). The laws do, however, provide for punitive action against noncompliant schools.

In all states, children who are suspected of having a hearing loss are entitled to free testing. The purpose, of course, is to identify, as early as possible, those children who require special assistance. In many states this is called “child find.” Once the identification is made, audiological services should include appropriate professional referral, habilitative measures (auditory training, language stimulation, speechreading, **speech conservation**), counseling and guidance, and determination of specific amplification needs (Johnson, 1994).

Childhood hearing loss delays the development of receptive and expressive communication skills, creating learning problems that reduce academic performance, create social isolation, lower self-concept, and restrict future vocational options. To help combat the educational implications of childhood hearing loss, ASHA (2004b) has detailed the responsibilities of the educational audiologist (Table 15.2).

A variety of placement options may be available for the formal education of children with hearing loss. These include privately and publicly funded institutions, residential and day schools, and public schools. Of all children in regular classrooms requiring special educational considerations, those with hearing impairment make up the largest groups (Flexer, Wray, & Ireland, 1989). Although classroom teachers have shown an interest in knowing more about their students with hearing loss, they admit that their knowledge base is inadequate for proper management (Martin, Bernstein, Daly, & Cody, 1988). In addition to educational management, teachers must have information about classroom acoustics, individually worn amplification devices, and systems to help improve the signal-to-noise ratios for children.

16. True/False

Numerous legislations exist for improved services for school children with handicaps although there is little recourse for noncompliant schools.

Clinical Commentary

When children are mainstreamed, direct contact with the classroom teacher is the best way to see that their needs are met. If intervention is handled diplomatically, audiologists and speech-language pathologists will find most teachers receptive and eager to learn how to help their students. Special help includes assigning preferential seating, providing maximum visual cues, encouraging the use of amplification,

providing written supplements to oral instruction whenever possible, and maintaining frequent contact with caregivers. Given the general scarcity of audiologists employed by schools, this important advocacy role for students with hearing loss is often carried out by the speech-language pathologist. It is axiomatic that any system of teaching children with hearing losses, in the classroom or speech and hearing clinic, will be most effective if it is complemented by a strong home program. Certainly academic progress must be monitored with the parents on a more frequent basis than with normal-hearing students.



For a listing of classroom management suggestions for students with hearing loss, see the “Handouts” section under Professional Resources on the Companion Website.

17. The role of audiologists and speech-language pathologists when working with children who have hearing loss is to _____ the parental decision-making process.

A parental decision to follow a certain course regarding a child's education and training may change, based on the reinforcement received for the efforts made and on new information acquired. The responsibility of the pediatric audiologist is to remain as a source of information and support to families, to follow up the initial diagnosis with regular hearing evaluations, and to assist with hearing aids and other listening devices as needed. Insightful clinicians must develop skills that allow them to facilitate, rather than to direct, families in the series of decisions that are so critical to fulfill the potential of children with hearing impairments.

The reader may have noted that a scrupulous attempt has been made throughout this book to minimize the use of the word *deaf*. Over 40 years ago, Ross and Calvert (1967) pointed out that the “semantics of deafness” might have a profound effect on the ability of a family with a child with a hearing impairment to cope with the problems that arise. The lay public, and to a large extent the professional community, have polarized people into two groups, those who hear and those who do not. When people are labeled “deaf,” it means to many that they cannot hear at all and that they will remain mute. This can inhibit the use of residual hearing and the development of spoken language. Ross and Calvert state that ignoring the quantitative nature of hearing loss may affect the child's diagnosis, interaction with parents, educational placement and treatment, and expectations for achievement.

Communication Methodologies

The precise modes of communication by which profoundly hard-of-hearing children should be educated continue to be debated. Increasing numbers of these children are receiving cochlear implants at a young age thereby circumventing their need for separate instructional communication modalities from their classmates. For children with profound hearing loss who do not have cochlear implants, many people believe that emphasis should be placed on speech, with amplification designed to take advantage of residual hearing. Strict adherents to this philosophy are often called *oralists*, who believe that, since all children live in a world in which communication is accomplished through speech, their adjustment is best made by teaching them to speak so that they will “fit in” with the majority of others.

Other experts believe that manual communication, by signs and fingerspelling, allows non-implanted children with profound hearing losses to communicate more readily, so that communication skills can be learned more quickly, and specific subjects can be taught. Additionally, the

manualists often believe that signing serves as a more useful communication system than speech for many of these children given that they will make adjustment to the nonhearing world where they will be accepted more completely.

The debate between manualists and oralists has a history that dates back to the earliest educators of those with hearing loss. While some are purists in their educational approach, others use a combination of signs and spoken messages to deliver their instruction. The following are some of the more familiar teaching methods.

American Sign Language (ASL). In American Sign Language, often called *Ameslan*, specific and often logical signs are created with the hands. Fingerspelling is used within ASL when no sign exists to represent a given word. (Figure 15.4 shows the manual alphabet.) ASL is often thought to suffer from inaccuracies in English grammar and syntax; however, it is not inaccurate when viewed as a language in its own right. ASL is considered by many educators to be a true language and is accepted by many high schools, colleges, and universities as a means of satisfying the foreign-language requirements.

For a demonstration of fingerspelling see the video titled “Manual Alphabet” in the Clinical Demonstrations section on the Companion Website.



Auditory-Verbal Approach. Formerly referred to as *unisensory* or *Acoupedics*, the auditory-verbal philosophy is based entirely on the use of audition and early amplification with hearing aids. This method stresses the auditory channel as the means for the development of spoken receptive and expressive communication skills.

Aural/Oral Method. Often called the multisensory or auditory-global approach, the aural/oral method attempts to tap the child’s residual hearing through amplification and to employ auditory and speechreading training. The child’s output is expected to be speech.

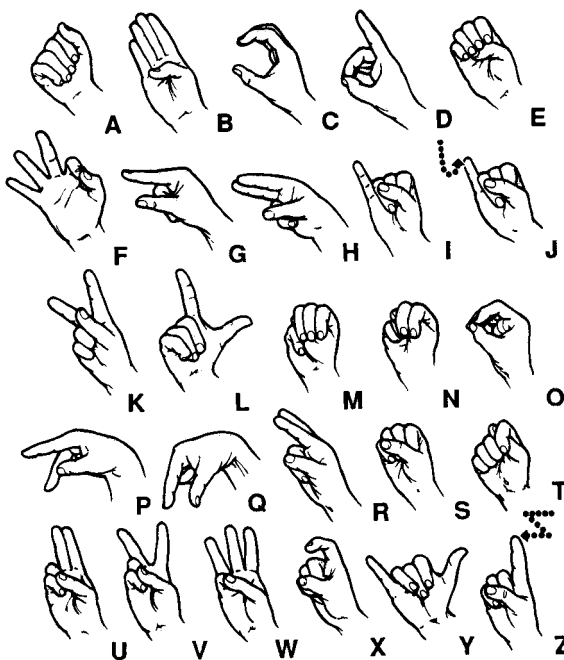


FIGURE 15.4 The manual alphabet.

Cued Speech. **Cued speech**, developed nearly half a century ago by Cornett (1967), was devised to aid speechreading and speech development and employs eight formed handshapes in four positions, which are made close to the face of a speaker so that they may supplement speechreading information. The cues assist in differentiating among sounds that appear to be the same on the lips (for example, /m/, /b/, and /p/). The child must simultaneously attend to both the speechreading and the cues, for the cues by themselves are meaningless.

Manually-Coded English. A variety of systems have been devised over the years that can all fall under the more general heading of **Manually-Coded English**. During educational instruction, these systems are usually accompanied by spoken English, which affords a *total communication* (TC) utilizing signs, residual hearing, and speechreading simultaneously. Proponents of this popular teaching methodology believe that language is learned more quickly and accurately through TC than by other methods, whereas critics maintain that it is unrealistic to expect some children to learn to listen, read lips, and follow signs at the same time.

Examples of Manually-Coded English include *Signed English* (SE), which follows the rules of English grammar; *Signing Essential English* (SEE 1) with specific signs for some articles and verbs as well as markers for tense and number; and *Signing Exact English* (SEE 2), which is a less than normally rigid system of signs that does not necessarily follow precise word order in a sentence. *Pidgin Sign English* (PSE) is a combination of ASL and some of the elements of systems that use sign markers to delineate plural and tense. An uncommon example of Manually-Coded English is *Linguistics of Visual English* (LOVE), which follows English word order but employs a slightly different written system. The *Rochester Method*, known as visible speech, employs the simultaneous use of speech and fingerspelling in a “writing in air” technique superimposed on normal speech. Certainly those systems of Manually-Coded English that do not follow English syntax may leave children at a risk of developing deficits in spoken English.

The Deaf Community

According to Vernon and Mindel (1978), the greatest psychological danger to the child with a profound hearing loss is the inability of the parents, and the professional specialists with whom they deal, to understand the problems involved. Their belief is that the frequent failure of amplification, even with speechreading and auditory training, testifies to the need for the early use of manual communication. They feel that children’s psychological and educational needs are not met by forcing them into artificial situations and insisting that they become something they are not—hearing persons. This belief that deafness need not be looked on as a handicap, but rather as a characteristic, is the philosophy of what has come to be called the “Deaf community.” The term *Deaf* (with a capital D) should be used to denote those who identify themselves with Deaf culture, while the term *deaf* (small d) describes the hearing status of the individual (Woodward, 1972). From an audiological standpoint, “deaf” is reserved for description of individuals whose hearing loss is so profound that the auditory channel cannot be used as the primary means for speech reception or speech and language development.

Lane (1992) maintains that the Deaf community should not be regarded as disabled, but should be thought of as a “linguistic minority,” with its own culture and language: American Sign Language. He speaks of the resentment of this group against the intrusion of the “audists” into the lives and educational decisions of deaf persons. This is a viewpoint that has become

18. The word “deaf” from an audiometric orientation implies a profound hearing loss that cannot effectively utilize auditory input. When this word refers to members of a distinct culture, it is _____.

increasingly prevalent. Lane (1987) also feels that the community of persons with severe to profound hearing losses is at odds with the professions that were designed to help it: "To achieve intellectual and emotional maturity at full participation in society most deaf children require an education conducted in their primary language, American Sign Language. . . ." Proponents of oral or combined oral and manual approaches to teaching children with hearing impairments may be just as adamant in their beliefs. Educational placement for children with hearing loss is an issue that is not soon to be easily resolved.

Management of Auditory Processing Disorders

Chapter 12 discussed assessment of disorders beyond the cochlea, including auditory processing disorders (APD). It should be noted that many of today's behavioral measures of central auditory function display their true value in their ability to describe the *communication impact* of auditory processing disorders. APD represents a disturbance or delay in the perception, recall, and organization of auditory information. These difficulties in the perceptual processing of auditory information within the central nervous system may be demonstrated by poor performance in sound localization and lateralization; auditory discrimination; auditory pattern recognition; auditory performance within a background of competing acoustic signals; or with degraded acoustic signals as well as difficulties with a variety of temporal aspects of audition (ASHA, 2004a). Whether for children or adults who have an auditory processing disorder, therapeutic intervention can be best designed and implemented when based upon the study of the resultant impact on communication.

Management of APD in Children

Behaviorally, children with APD demonstrate difficulty paying attention or remembering information, require more time to process information, exhibit poor listening skills, and display problems following multistep instructions. In addition, they may have behavior problems and lower academic performance than expected for children with normal hearing and normal intelligence. These children may show a lack of attention to auditory stimuli, thereby increasing distractibility; a decrease in auditory discrimination and localization abilities, making the comprehension of speech more difficult; and difficulty with auditory figure-ground differentiation, resulting in a decreased ability for selective attention. Difficulties in auditory processing may be associated with a variety of conditions including dyslexia, attention deficit disorder, autism, autism spectrum disorder, specific language impairment, pervasive developmental disorder, or developmental delay. Often the diagnosis of APD will begin with the child's pediatrician, who will systematically rule out other disorders that may have similar symptoms.

Frequently, APD is not evident until a child enrolls in school and the previous one-on-one home learning environment is replaced by a large classroom with an unfamiliar set of visual and auditory distractions. The child's self-image can deteriorate rapidly as he is repeatedly told he has normal intelligence and hears normally, yet he observes he is not performing as well as his peers.

Therapeutic intervention for APD in children can be best designed and implemented when based upon the study of the resultant impact on communication. Often the audiologist and speech-language pathologist will work together as a team in the management of APD. Research is ongoing to better understand APD and related childhood disorders and what might comprise the best management approach with continuous evaluation of the effectiveness of any treatment employed.

Classroom management suggestions (Clark, 1980; Hall & Mueller, 1997) and classroom sound-field amplification or personal FM systems to improve signal-to-noise ratios (see Chapter 14)

can be of benefit for children with APD. Classroom modifications to further enhance the signal-to-noise ratio may be as simple as placing tennis balls on the feet of chairs, adding curtains for sound absorption, and providing preferential seating for the student.

While it may be audiological measures that lead to the diagnosis of APD, it is the assessment contributions of the speech-language pathologist that shed greater light on language ability and the functional deficits of communication that may point to remediation needs. Frequently, speech-language pathologists may work with the child with APD to improve language skills, phonemic recognition, and auditory memory as well as provide auditory training to enhance specific auditory deficits including sequencing, auditory attention, auditory pattern recognition, auditory discrimination, auditory figure-ground differentiation, and localization.

Some children with auditory processing problems and concomitant language-learning impairment have benefited from speech perception training incorporating recorded speech with speech sound prolongations accompanied by amplification of some of the more salient acoustic features of speech (Cinotti, 1998). This program, known as Fast ForWord, consists of seven games targeting select aspects of language processing. A computer-based program known as Earobics designed for children with literacy problems has also been reported to be useful in the remediation of auditory skills for children with APD.

Auditory integration training (AIT) is another approach purported by some to retrain the auditory system and decrease what proponents refer to as “hearing distortions.” AIT, a method that has met considerable skepticism over the years, is based on the theory that prolonged listening to loud, frequency-altered music forces the auditory system to respond to a larger than normal frequency and intensity range for sound resulting in a greater normalization of the auditory system. The American Speech-Language-Hearing Association concluded that AIT has not met scientific standards for efficacy to justify the use of this intervention by either audiologists or speech-language pathologists (ASHA, 2004e). However, the association did recommend a reexamination of its position should controlled studies that support AIT’s effectiveness become available.

Academically, it is imperative that either the speech-language pathologist or audiologist advise the teacher of a child with APD of the ramifications of the disorder and the treatment that is being given. Explaining the difference between hearing the sounds of speech and fully comprehending their meaning may be useful in the teacher’s understanding of the need for the child to associate the spoken word with its referent to aid comprehension. The greater the teacher’s understanding of APD, the greater will be the child’s learning success. Similar classroom management suggestions to those given to teachers of children with peripheral hearing deficits are also helpful to the child with APD.

19. True/False
The use of classroom suggestions to facilitate learning for children with hearing loss can be beneficial for children with APD.

Clinical Commentary

While speech-language pathologists and audiologists may work collaboratively on many fronts within the management of communication disorders, such collaboration may be greatest in the assessment and management of auditory processing disorders in children. Clinical endeavors overlap for these two groups of professionals, with audiologists providing assessment of both the peripheral and central auditory systems and providing management of identified disorders, while speech-language pathologists provide assessment of language skills and provide appropriate intervention in this area.

Classroom management suggestions for children with APD may be found in the Professional Resources section of the Companion Website.



Management of APD in Adults

Adults with cochlear hearing loss frequently have difficulties in speech sound recognition due to changes in the auditory periphery that attenuate and distort sounds. As some patients age, presbycusis may no longer be simply a cochlear phenomenon but may also impact the central auditory nervous system. This added central presbycusis can make the processing of spoken language even more difficult than it might be with cochlear hearing loss alone, especially when speech is presented rapidly or in the presence of competing acoustic signals. Clinically, audiologists frequently see elderly patients whose performance with amplification is significantly poorer than expected based upon the audiological evaluation of the peripheral auditory system. Assessment of these patients' speech-recognition performance with auditory competition as discussed in Chapter 5 can provide significant clinical insights before proceeding to hearing loss treatment recommendations.

Within rehabilitation, the audiologist's greatest contributions for adults with auditory processing difficulties or central presbycusis often come through the improvement of sound input through signal-to-noise enhancement. This may be best accomplished through instruction on restructuring of the listening environment and the recommendation of personal FM amplification and various other assistive listening devices.

20. Adults who may experience both peripheral and central auditory problems are most benefited by technology that improves the _____.

See Chapter 14 for discussion of assistive listening devices, as well as the Learning Supplements section of the Companion Website.



The general loss of neurons and brain plasticity that accompanies the aging process may indeed justify a more compensatory approach in the management of auditory processing disorders with adults. In addition, to improve the overall listening environment for adults with central presbycusis, audiologists may provide general communication guidelines that have proven beneficial to patients with more peripheral hearing loss (Clark & English, 2004; Trychin, 1994). The high incidence of some degree of auditory processing difficulties among older adults, and the need to make appropriate recommendations when present, has led many audiologists to routinely incorporate means of screening for the presence of central presbycusis with this population.

Suggestions for enhanced communication with hearing loss that may prove useful for adults with APD may be found in the Professional Resources section of the Companion Website.



While the underlying origins of APD may differ in children and adults, the overall goal of intervention is the same: an improvement in listening skills and spoken-language comprehension. Toward this end, management efforts may be aimed at restructuring listening environments and improving communication strategies coupled with specific auditory processing training. Interested readers may want to consult the suggested readings at the end of this chapter for details of a multifactor approach to remediation.

Management of Tinnitus

Tinnitus has been mentioned several times in this book. Complaints of ear or head noises go back through recorded history and accompany, to some degree, almost every etiology of hearing loss.

As many as 40 to 50 million Americans have been reported to experience tinnitus with or without accompanying hearing loss (Henry, Jastreboff, Jastreboff, Schechter, & Fausti, 2002). While many people with tinnitus do not experience significant deleterious effects, tinnitus can have a negative emotional impact on individuals, affecting concentration, sleep patterns, employment, personal relationships, and social functioning. Indeed, as many as 2.5 million Americans report tinnitus to be so significant as to be considered debilitating (Davis & Refaie, 2000).

While early measures of perceived tinnitus loudness suggested levels ranging from 1 to 20 dB SL (Graham & Newby, 1962), later measurement methods are more commensurate with the levels of tinnitus patients' distress, yielding values ranging from 8 to 50 dB SL (Goodwin, 1984). The prevalence of tinnitus in children may be greater than commonly realized, as children are probably less likely to report these sounds unless questioned (Clark, 1984). Graham (1987) reported that more than 60% of surveyed children with hearing loss requiring amplification experienced some degree of tinnitus.

Although the origin of tinnitus has long been a source of debate among clinicians and researchers, recent investigation of cerebral blood flow suggests that the source of tinnitus may lie within auditory cortical regions of the brain rather than the cochlea itself (Lockwood et al., 1998). This would suggest that it may not be damage to the cochlea that gives rise to tinnitus, but rather aberrant changes within the central auditory pathways secondary to more peripheral impairment. However, the origin is not known for certain. It can probably arise from different sites within the auditory system, and if known, would probably not guarantee that an absolute therapeutic intervention could be developed (Sandlin & Olsson, 2000).

Fagelson (2007) describes an association between tinnitus and **posttraumatic stress disorder (PTSD)**. PTSD is a condition that can produce a variety of psychological and physiological symptoms and is seen frequently among combat veterans. The stresses of war and the exposure to dangerously high levels of noise can produce PTSD, with the latter also frequently resulting in noise-induced hearing loss with associated tinnitus. The presence of both these conditions in the same individuals can cause synergistic interactions that can be devastating, a fact that audiologists must constantly take into consideration in dealing with these cases.

Figure 15.5 summarizes many of the contributors to the perception of tinnitus, which has been variously described as “ringing,” “crickets,” “roaring,” “hissing,” “clanging,” “swishing,” and a host of other similar adjectives. Tinnitus of a tonal quality is reported to occur more frequently than “noise-type” tinnitus and is judged by patients to be more annoying (Press & Vernon, 1997). With the formation of the American Tinnitus Association (DeWeese & Vernon, 1975), consciousness has been raised on the subject, and professionals have learned to heed the complaints of tinnitus sufferers. Other than the use of masking sounds to cover up the tinnitus—for example, a radio or white-noise generator at night and hearing aids during the day—little help was available until about 25 years ago. Treatment has included drugs such as vitamins and vasodilators and such surgeries as labyrinthine or vestibular nerve destruction, nerve blocks, and cognitive therapy, all with varying results.

Audiologists, frequently consulting with a multidisciplinary team, evaluate tinnitus, develop management strategies for combating the effects of tinnitus, and implement treatment and rehabilitation plans for tinnitus sufferers (AAA, 2000). Toward this end, the wearable tinnitus-masking unit has enjoyed some marginal popularity. Most such devices are similar to behind-the-ear and in-the-ear instruments (see Figure 14.6C and E) and are manufactured by some hearing-aid companies. The tinnitus masker produces a band of noise that surrounds the

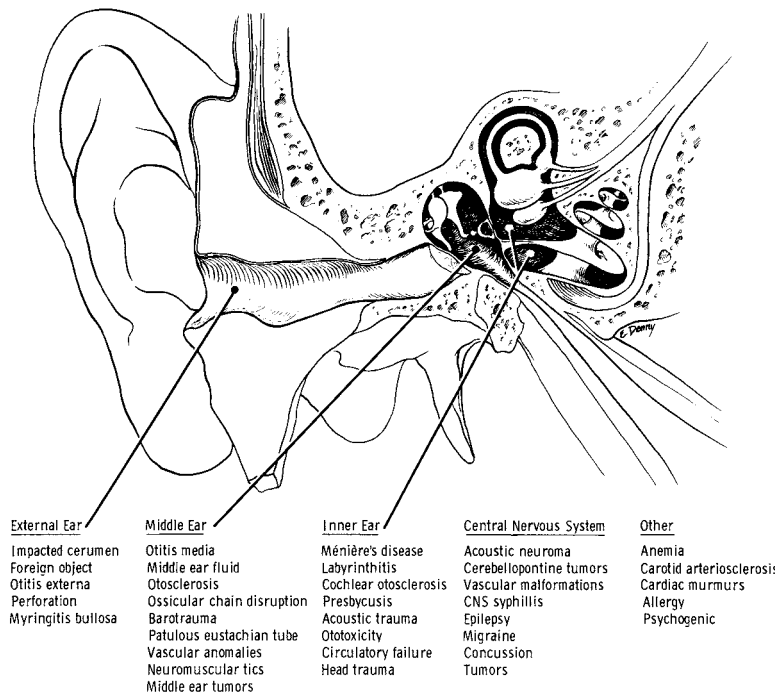


FIGURE 15.5 Possible contributors to the perception of tinnitus. (Courtesy of Dr. Ross Roeser)

frequency of the tinnitus. When no specific frequency or noise band is reported as characteristic of the tinnitus, a broadband signal may be used as the masker. With patience and gradual adjustments, a close match to a patient's tinnitus can be obtained.

Most patients have given disappointing reports on the effects of tinnitus maskers, but a few are extremely satisfied with the results. Some claim that not only is the tinnitus relieved by what they observe to be external sounds preferable to their own tinnitus, but also the tinnitus is temporarily absent after the masking device is removed. Although it is not completely understood, this effect may be explained by some residual inhibition in the auditory system. If a hearing loss is present, hearing aids with appropriate gain for the hearing loss often serve as effective tinnitus maskers.

The principles of biofeedback have also been applied for tinnitus relief. Biofeedback allows individuals to monitor their own physiological activity by attaching recording electrodes to special parts of the body; these permit the patient to observe and control the activity. Some patients have learned to monitor and suppress their tinnitus through biofeedback techniques.

Tinnitus Retraining Therapy (TRT) has been shown to provide patients with a means to habituate to the presence of their tinnitus (Jastreboff & Hazell, 1998). This therapy is based upon the observation that the auditory system's contribution to the annoyance of tinnitus may be secondary to that of the limbic (emotional) and the autonomic nervous systems. TRT requires a substantial amount of direct work with patients, but when done properly yields a success rate for reducing tinnitus annoyance greater than 80%.

21. While tinnitus sufferers are frequently told that there is nothing to do for their disorder, in reality there are varieties of treatment options with varying degrees of success including

_____, _____,
_____, and _____.

A comparative investigation between the clinical efficacy of TRT and the use of tinnitus maskers demonstrated significantly greater improvements with TRT (Henry et al., 2006).

One of the more recent tinnitus treatment approaches known as Neuromonics (Davis, 2006) is based upon a systematic desensitization of the tinnitus signal through a device that permits an intermittent, momentary perception of tinnitus within a pleasant and relaxing acoustic stimulus. Neuromonics tinnitus treatment reportedly provides rapid and significant reductions in the perceived severity of tinnitus symptoms and a subsequent improvement in the reported quality of life among treated tinnitus sufferers (Davis, Paki, & Hanley, 2007).

Some patients' complaints of tinnitus are much more dire than others with similar amounts of hearing loss in whom one might predict a similar type and degree of tinnitus. Schechter, McDermott, and Fausti (1992) liken the affliction from tinnitus to experiences of pain. They suggest that, given a certain amount of neural activity stimulating the pain centers of the brains of two individuals, the experiences might be quite different, being modified by higher brain centers, and by such factors as mood, personality, and culture. They also suggest that the effects of tinnitus on any given individual's personal life may, at least in some cases, be influenced by that person's psychological state. Given the interactions between the often unknown physiological base of tinnitus, and the psychological reaction to it, the phenomenon of tinnitus continues to be perplexing.



For descriptive information for patients with tinnitus, see the handouts section under Professional Resources on the Companion Website.

Hyperacusis

Some patients with tinnitus report a decreased tolerance to loud sounds. This phenomenon known as **hyperacusis** has also been termed *soft sound sensitivity syndrome*. The majority of sufferers report their *hyperacusis* to be equally disturbing as, or worse than, their tinnitus (Reich & Griest, 1991). Contrary to the common belief that hyperacusis represents an exceptionally acute sense of hearing, this disorder is more accurately described as a collapse of loudness tolerance. The threshold of loudness discomfort for the patient with hyperacusis has been reported to be inversely related to frequency, with less loudness tolerance as frequency increases. The threshold of discomfort for these patients may be as low as 20 to 25 dB SL for low-frequency sounds (e.g., 250 Hz), declining to as little as 5 dB SL or less for sounds greater than 10,000 Hz (Vernon & Press, 1998). Moorehouse, Waddington, and Adams (2005) report on numbers of individuals complaining primarily of difficult-to-bear loudness of low-frequency sounds. Hyperacusis is a phenomenon separate from loudness recruitment, often considered to result from decreased inhibition within the central auditory system.

Those individuals with hyperacusis may react in a frightened or startled fashion to common sounds such as the telephone ringing or the noise of a vacuum cleaner. These persons may resort to the use of hearing protection to better endure their daily lives, although overprotection of the ears may actually cause a worsening of the condition. In addition to shunning protection of the ears from everyday sounds, audiological rehabilitation has been successful with some patients with hyperacusis through a series of desensitization exercises over a protracted time (Vernon & Press, 1998). Clearly much more is to be learned about the phenomenon of hyperacusis.

22. True/False

An effective treatment for hyperacusis is the use of ear plugs to soften the intensities of bothersome sound.

Vestibular Rehabilitation

As discussed in Chapters 11 and 12, various lesions of the cochlea and beyond the cochlea related to disease, toxins, trauma, or syndromes can lead to symptoms manifesting as recurrent or constant dizziness, lightheadedness, or vertigo. Indeed, it is estimated that at least half of the United States population will be affected by vestibular or balance problems at some time within their lives and that these disturbances can be present within both the pediatric and adult populations (AAA, 2004a). Vestibular problems, which can be acute, chronic, and debilitating for many individuals, can create a blurring of vision, difficulty with balance, dizziness, spatial disorientation, and frequent, sometimes devastating, falls.

While some argue that the audiologist’s scope of practice should be defined by communicative function, others successfully argue that the anatomical origins of vestibular maladies place their assessment and rehabilitation within the audiologists’ purview. Indeed, vestibular assessment and management are within the audiologists’ scope of practice (AAA, 2004b; ASHA, 2004d), and many audiologists have built their careers around vestibular diagnostics and treatment through exercise therapy, habituation, and balance retraining.

Both audiologists and some physical therapists provide services in vestibular rehabilitation or balance retraining with specific goals for their patients (see Table 15.3). These services may take the form of habituation or adaptation exercises, canalith repositioning, and balance retraining exercises. Vestibular habituation or adaptation exercises rely on the brain’s ability to retrain its response to sudden movements. Patients are instructed to perform specific movements or assume specific positions that provoke their dizziness and asked to repeat these movements until the brain habituates the response. Canalith repositioning has been found to be an effective treatment for many who suffer from benign positional vertigo and involves moving the patient’s head in a sequence of positions in order to reposition the otoconia within the semicircular canals. Balance retraining exercises are designed to improve the coordination of muscle responses as well as to enhance the integration of sensory information from the eyes, ears, and muscle receptors governing proprioception. If patients are found to have an impaired ability to maintain their gaze and focus, visual-motor exercises for gaze stabilization and eye-hand coordination may also be provided.

The extent of preparation in vestibular assessment and management that audiology students attain in their professional preparation has increased significantly in most universities with the advent of the professional doctorate in audiology. When training is not sufficient to undertake the responsibilities inherent within vestibular diagnostics and rehabilitation, it is a practitioner’s ethical responsibility to ensure the acquisition of requisite knowledge and skills, possibly through postgraduate education.

23. True/False
Audiology scope of practice has expanded to include both vestibular diagnostics and some forms of treatment.

TABLE 15.3 Goals of Vestibular Treatment

- To decrease the frequency, intensity, and duration of dizziness episodes
- To improve an individual’s functional balance
- To decrease the severity of the related symptoms of nausea, headache, and lightheadedness
- To improve upon the individual’s performance of daily activities
- To reduce falls or risk of falling
- To develop compensation strategies for coping with disequilibrium and dizziness and the accompanying anxieties

Clearly, there is a need for the treatment of vestibular disorders, as a complaint of dizziness is one of the most common within the primary-care physician's office, with concerns of balance being one of the most frequent reasons for medical consultation and hospital admission for those over age 65 (Desmon, 2000). Given the possible existence of a complicated medical history for the patient with a balance disorder, evaluation and treatment should follow medical evaluation to ascertain if there are any identifiable and medically manageable origins to the stated complaints.

Multicultural Considerations

Ethnic, cultural, and linguistic diversities have been changing throughout the United States for decades. Diversity within our population may arise from a variety of influences including ethnicity, religion, sexual orientation, geographic region, socioeconomic levels, educational background, mental/physical disability, and age-based peer groups (ASHA, 2004c). Approximately one out of every three Americans is nonwhite, with Hispanics constituting the most rapidly growing minority group in the United States. The percentages of culturally and linguistically diverse groups among school-age children was nearly twice that of the general population in the latter part of the 20th century (U.S. Bureau of the Census, 1990) and will comprise 22% of the school-age population by 2010 (U.S. Bureau of the Census, 2000).

Professionals have an obligation to become familiar with cultures apart from their own and to recognize the diversity existent within a given culture (Atkins, 1994; Ballachanda, 2001; Clark, 1999; Clark & English, 2004; Roseberry-McKibbin, 1997). Certainly, language differences between audiologists and patients can directly influence both the evaluation and the subsequent counseling that is provided (Flores, Martin, & Champlin, 1996). But beyond this, patients from different cultural backgrounds bring to the clinic values and assumptions that may in themselves be foreign to the clinician. Variations within culturally acceptable family dynamics and cultural influences on outward interactions with those perceived to be in positions of authority (like audiologists) can have a direct impact on acceptance and implementation of professional recommendations.

It has been estimated that only about 7% of audiologists and speech-language pathologists identify with a racial or ethnic minority background (ASHA, 2002a). Most Americans are proudly immersed within the dictates of Western culture to an extent that unfortunately breeds considerable ethnocentricity. When an employment setting brings one into repeated contact with persons from a different heritage, it behooves clinicians to become familiar with aspects of the cultures of their patient base. Such familiarity allows us to recognize attitudes and beliefs that need to be acknowledged and accounted for within rehabilitative planning. Roseberry-McKibbin (1997) provides an extensive overview of culturally diverse patients who may seek services from professionals in communicative disorders. As she points out, open and honest discussions, so common to Americans, are not the norm for many cultures. Japanese social norms, for example, dictate that one seeks out harmony and avoids conflict. Such ingrained social patterns do not interface well with some aspects of patient management.

Some Hispanics and Asians believe that only overtly visible physical disabilities merit intervention, a view that may greatly impede attempts at hearing rehabilitation. Individuals from some cultures may feel uncomfortable when professionals ask for family participation in the rehabilitation program because they believe such matters are solely within the province of the professionals. Others may feel attempts at intervention are inappropriate outside the context of family influence.

Certainly, not all people from different linguistic and cultural backgrounds remain steeped within the cultural constructs of their forebears. This is as important for clinicians to hold in mind as is the need for acceptance of differences that may be encountered. When cultural diversities arise, it is paramount that professionals strike a balance between accepting patient and family beliefs and encouraging exploration of available rehabilitative options.

For information on how best to interact within a clinical setting with patients from different cultural backgrounds, the reader is referred to www.culturegrams.com and to the Center for Assessment and Demographic Studies, Gallaudet University, Washington, DC.

As described earlier, audiologists must remain cognizant of the views of those who align themselves within the culture of the Deaf community. Regardless of one's views on Deaf cultural issues, the Deaf community can serve as a valuable resource in hearing-loss management for families and professionals alike.

Evidenced-Based Practice

Practitioners of audiological treatment, like providers of intervention for any human disorder, should provide evidence of benefit derived for the services rendered. This is the underlying principle of **evidence-based practice**, which is most concisely defined as a “conscious, explicit, and judicious use” of the best and current evidence available when making decisions about patient care (Sackett, Rosenberg, Gray, Haynes, & Richardson, 1996). Evidence-based practice utilizes a combination of the practitioner's clinical experience and available research on the interventions provided.

The effective delivery of clinical practice that is based on evidence supporting the best of current procedures and technology is a five-part process entailing a definition of the problem, searching for available evidence to support the contemplated treatment, critically appraising the evidence, detailing recommendations, and finally assessing the outcome of the treatment delivered (Cox, 2005). Certainly integral to the success of evidence-based practice is the practitioner's ability to allow and encourage the patient's viewpoints and preferences, to elicit the patient's concerns, and to help to develop a level of reasonable expectation for success with the rehabilitative intervention. It is the practitioner's responsibility to formulate interventions that offer the best solutions available for each unique individual.

24. It is the responsibility of all speech-language pathologists and audiologists to provide services that are based upon supportive evidence. The three components of evidence-based practice include _____, _____, and _____.

Outcome Measures

Many aspects of healthcare are often delivered with insufficient consideration given to the evidence available that might direct one toward a different approach, or to documentation of the outcomes derived from the approach taken. In audiological treatment the desired outcome may not necessarily be a resolution of the hearing impairment. Rather, treatment is more directly aimed at compensating for the effects of hearing impairment. The provision of services that do not benefit the patient is a violation of professional ethics and highlights the importance of documenting the positive outcome of audiological treatment.

Given the wide diversity in the patients seen and the auditory and balance problems they may manifest, it is not surprising that there is not a single, best approach to measure outcomes in the practice of audiology. Ideally, the efficacy of treatment provided should be documented

25. Outcome measures should be routine assessments for speech-language pathologists and audiologists as a means to _____.

through objective measures comparing performance on select tests prior to and following intervention and subjective measures of patients' and family's perceptions of improvement. The latter may most easily be accomplished through a comparative re-administration of the self-assessment questionnaire that may have been given when obtaining case history information. Self-assessment questionnaires to gauge the perceived impact of a disorder on an individual are available for hearing loss, tinnitus, balance difficulties, and other areas or problems treated by audiologists.

EVOLVING CASE STUDIES

Through the course of this book you have followed four case studies presenting four different types of audiological challenges that you may be called upon in the future to face with your patients. Frequently, results obtained on patients necessitate audiological intervention that transcends diagnostic evaluation. It is within the realm of the treatment we provide to patients that audiologists reach their highest levels of professional autonomy. There is perhaps no greater responsibility for audiologists than to ensure that their patients' communication function is restored as fully as possible so that they may attain their greatest potential in all areas of their lives. Toward this end we turn to a final look at our continuing case studies.

Case Study 1: Conductive Hearing Loss

In many instances, conductive hearing loss is successfully treated medically and functional hearing is regained following intervention. The audiologist's role toward this end lies in the provision of an accurate evaluation prior to treatment and determination posttreatment that no residual hearing impairment remains. Not only are these losses most amenable to medical intervention, it is these patients who frequently perform most successfully when audiological intervention is required. Due to the absence of active otologic pathology, the 23-year-old woman in this case study was fitted with air-conduction hearing aids, as discussed in Chapter 14. As with any patient who acquires amplification, it is imperative that she be scheduled for routine (annual or semiannual) visits to service her hearing aids and monitor her hearing for any change in sensitivity. Given normal cochlear function, it is unlikely that she will experience the same amplification limitations experienced by the patient in Case Study 2. As such, she may not require the same active spousal involvement in the treatment process nor the same hearing loss management guidelines.

Case Study 2: Sensory/neural Hearing Loss

As you may recall from Chapter 14, this 76-year-old patient has a bilaterally symmetrical, mild to moderate sensory/neural hearing loss of cochlear origin, accompanied by reduced speech recognition. It was noted by his wife at the outset in our first visit to this case study in Chapter 2 that this patient has significantly reduced his interactions with others, particularly avoiding movies, theater, and religious services. Our goal in the treatment process with the selection and fitting of appropriate amplification that began in Chapter 14 continues here. Even the best hearing aids can only partially restore lost hearing function. While the benefit obtained can be substantial, noted deficits will remain. It is the audiologist's responsibility to ensure that both the patient

and any attending significant other, in this case the wife, are fully aware of the expected benefits and limitations of hearing loss intervention.

To offset the remaining constraints on this patient's hearing, additional hearing assistance technologies that may improve signal-to-noise ratios in public arenas should be demonstrated. In addition, it is imperative that the audiologist provides direct instruction in hearing-loss management. As discussed in this chapter, instruction may include identification of sources of communication breakdown (including speaker, listener, and environmental factors) and actions that may be taken to combat each of these in direct attempts to reduce communication stress. While discussions of this sort are always best conducted in a group setting, when this is not possible, these points should be covered with the patient and spouse, and they should be provided with accompanying handouts.

To ensure long-term satisfaction, this patient should be scheduled to return annually or semiannually for servicing of his hearing instruments and monitoring of his hearing levels with modification to his hearing aid's circuit settings made as needed. If it has not been completed before, his first six-month check would be a good time to repeat any self-assessment measure that was given during his initial evaluation. A comparison of results can quickly document self-perceptions of the benefit received from the intervention given. Such results are becoming increasingly important to audiologists who, like any other healthcare professional, need to justify the efficacy of the services they provide to insurance companies and other third-party payers.

Case Study 3: Erroneous Hearing Loss

Our clinical responsibilities with patients who exhibit erroneous hearing loss not only includes identification of the behavior, but also determination of true organic hearing levels when possible and referral for professional counseling when indicated. Discussing test findings with a patient whose test results are clearly invalid and without a clear organic basis for the exhibited hearing loss can be one of the more disconcerting and frustrating consultations in which audiologists engage. As discussed in Chapter 13, a direct confrontation with the patient who exhibits erroneous hearing loss is rarely fruitful. If the clinician assumes responsibility for the inaccurate test results by, for example, blaming poor instructions or equipment difficulties and begins the test again, this may allow the patient to save face and provide more accurate results. It may be helpful to let the patient know that, if difficulties in attaining accurate results on the retest continue, there are other more objective measures that may be required. If true organic thresholds cannot be voluntarily obtained from the patient and are believed necessary for disposition of the case, ABR testing should be recommended. Short of this, any report to the referral source should speak only to the discrepancies in the test findings and the lack of requisite cooperation to secure accurate results.

It is easy for clinicians to become annoyed with noncooperative patients, especially those who take more than the usually allotted time and interfere with the schedule. It is most important that the audiologist play a nonaccusatory role and avoid any terms that might be considered pejorative. The possibility of legal action has to be carefully avoided. Perhaps even more important is the fact that, especially in the early encounters with patients with erroneous hearing loss, it is not possible to know the extent of any emotional fragility, and we do not want to contribute to any psychological difficulties the patient may be experiencing.

Case Study 4: Pediatric Patient

Through several visits with this patient, hearing tests have revealed a severe-to-profound sensory/neural hearing loss for this 3-year-old girl who possesses no meaningful speech and language. In Chapter 13 it was recommended that this girl be fitted with relatively powerful digital behind-the-ear hearing instruments with direct audio input capabilities to accommodate a personal FM system in order to enhance the signal-to-noise ratio of the speech she hears. It was also expected that she would continue with the referring speech-language pathologist for individual and group speech and language stimulation programs. Monitoring of this child's progress in therapy will be one component in any future considerations that may be made toward possible cochlear implantation.

Throughout continued intervention with this patient, the audiologist and the speech-language pathologist must remain cognizant that, nearly universally, families in this situation are undergoing great, prolonged, and painful adjustments. Professional codes of ethics dictate that referrals be made when best practices dictate that this should be done. Certainly, referral to a parent support group would be an excellent step for this child and her family, which may include siblings, grandparents, or other relatives. In addition, support groups should be investigated for grandparents and for any siblings who may be old enough to have their own questions and concerns, expressed and unexpressed, about this new dimension to their home life. The availability of genetic counseling will also need to be broached with the parents, who at some point, often early in the process, will question the origins of this hearing loss and the possibility of its recurrence within their own immediate family or the future families of their children. Privacy legislation dictates that referral to any outside agency or professional person must be accompanied by a signed release from the parents to share pertinent information.

Summary

Diagnosis of the type and degree of a patient's hearing loss is an essential beginning to audiological (re)habilitation. For proper management, the audiologist must become sophisticated in the intricacies of history taking. The importance of a proper professional relationship between the audiologist and the patient (or family) cannot be overstated. Advising and counseling sessions greatly affect the overall management of those with hearing impairment. Audiologists also must maintain good relationships with other professionals who may be involved in the rehabilitation of the patient. Proper relationships are strongly influenced by the exchanges among professionals, such as letters and reports.

Audiologists should be responsible for the total program of audiological rehabilitation of the adult patient with a hearing loss. They must make the determination of the need for special measures, such as speechreading, communication training, auditory training, the acquisition of hearing aids, tinnitus therapy, or hyperacusis desensitization. If hearing aids are indicated, the audiologist should figure prominently in the selection and fitting procedures.

When working with children, audiologists must muster every resource at their disposal, including interactions with caregivers and other professionals, in designing approaches that will maximize the human potential in every child with a hearing loss. To do less is a disservice to the children, whose futures may be profoundly affected by professional decisions.

Study Questions

1. In what ways do the approaches to audiological rehabilitation differ for children and adults?
2. List the data you would include in a report sent to different specialists with a common interest in your patient. In what ways are the reports similar and dissimilar?
3. List the first five questions you would ask when recording a patient's history.
4. Design a case history form that might be suitable for (a) adult patients and (b) pediatric patients.
5. How may tinnitus and hyperacusis be treated?
6. How might acceptance of an acquired hearing loss be improved?
7. How would you approach the counseling of the parents of a child who has just been diagnosed with a hearing loss?
8. What are some of the topics that might be included in an adult hearing therapy class?
9. List the training and educational options for children with severe hearing impairments.

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Endnote

1. For Alois Alzheimer, German neurologist, 1864–1915.

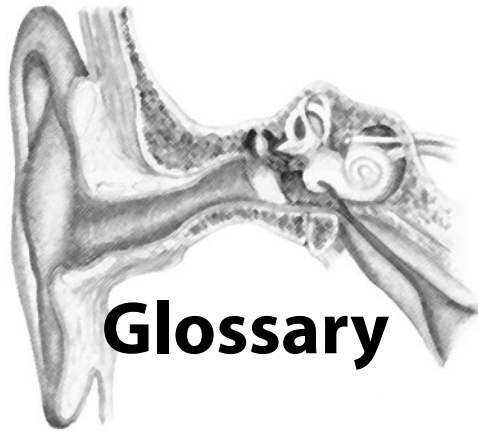
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Glossary

Acoustic admittance The total flow of energy through the middle-ear system expressed in mmhos (millimhos); the reciprocal of impedance, which is expressed in ohms.

Acoustic feedback The whistling sound that is created when the signal leaving the receiver of a hearing aid leaks back into the microphone and is reamplified.

Acoustic gain The difference, in decibels, between the intensity of the input signal and the intensity of the output signal in a hearing aid.

Acoustic impedance The total opposition to the flow of acoustic energy (as in the plane of the tympanic membrane). It consists of mass reactance, stiffness reactance, and frictional resistance and is influenced by frequency.

Acoustic neuritis Inflammatory or degenerative lesions of the auditory nerve.

Acoustic neuroma A tumor involving the nerve sheath of the auditory nerve.

Acoustic reflex Contraction of one or both of the middle-ear muscles in response to an intense sound.

Acoustic reflex arc The path of an acoustic stimulus that ascends from the outer ear to the brainstem and then descends via the facial nerves on both sides of the head to innervate the stapedial muscles in both middle ears.

Acoustic reflex decay A decrease in the magnitude of the middle-ear reflex that occurs with constant acoustic stimulation.

Acoustic reflex threshold (ART) The lowest intensity at which a stimulus can produce the acoustic reflex.

Acoustic trauma notch A precipitous increase in hearing loss in the 3000 to 6000 Hz range, with recovery of hearing function at higher frequencies. It is usually, but not exclusively, associated with patients with noise-induced hearing loss.

Acquired immune deficiency syndrome (AIDS) See *Human immunodeficiency virus*.

Action potential (AP) A change in voltage measured on the surface of a neuron when it fires.

Acute A condition characterized by rapid onset, frequently of short duration.

Aditus ad antrum A space in the middle ear containing the head of the malleus and the greater part of the incus. It communicates upward and backward with the mastoid antrum.

Afferent Nerves that carry impulses from the periphery toward the brain.

Air-bone gap (ABG) The amount by which the air-conduction threshold of a patient exceeds the bone-conduction threshold at any frequency in the same ear.

Air conduction The course of sounds that are conducted to the inner ear by way of the outer ear and middle ear.

Allele One of two or more forms of a gene occupying corresponding locations on corresponding chromosomes.

Alternate binaural loudness balance (ABLB) test A procedure that tests for recruitment in unilateral hearing losses. The growth of loudness of pure tones in the impaired ear is compared with that of the opposite (normal) ear as a function of increasing intensity.

Alzheimer's disease A condition associated with aging that accounts for some 60–70% of senile dementias and is associated with a variety of symptoms, most notably memory loss.

American National Standards Institute (ANSI) An organization established to oversee the creation and use of guidelines that impact all centers of U.S. business. These include acoustical devices like audiometers, construction equipment, and much more. It is also involved in accreditation of a variety of programs.

Americans with Disabilities Act A public law (P.L. 101-336) passed in 1990 enacted to provide equal opportunity for individuals with disabilities.

Amplitude The extent of the vibratory movement of a mass from its position of rest to that point farthest from the position of rest.

Amplitude distortion The presence of frequencies in the output of an electroacoustic system that were not present at the input,

resulting in a disproportional difference between the input and output waves.

Ampulla The widened end of each of the three semicircular canals where they return to the utricle. Each ampulla contains an end organ for the sense of equilibrium.

Analog hearing aid An amplification system in which the electrical signal is analogous to the input acoustical signal in frequency, intensity, and temporal patterns.

Anechoic chamber A specially built room with large wedges of sound-absorbing material on all walls, floor, and ceiling whose purpose is to provide maximum sound absorption and to keep reverberation to an absolute minimum.

Annulus The ring of tissue around the periphery of the tympanic membrane that holds it in position at the end of the external auditory canal.

Anotia Absence of the pinna.

Anoxia Deprivation of oxygen to specific cells of the body affecting their normal metabolism.

Aperiodic sound A complex sound that varies randomly over time and does not have a fundamental frequency.

Aperiodic wave A waveform that does not repeat over time.

Apgar test A method for evaluating the status of infants immediately and shortly after birth. Observations are made of the child's respiration, heart rate, muscle tone, color, and reflex irritability.

Artificial ear A device for calibrating air-conduction earphones. It consists of a 6 cm³ coupler to connect an earphone to a condenser microphone with cathode follower and a meter that reads in dB SPL. When calibrating insert earphones, a 2 cm³ coupler must be used.

Artificial mastoid A device for calibrating bone-conduction vibrators consisting of a resilient surface that simulates the vibrating properties of the mastoid process of the skull and an accelerometer. It is connected to a meter that reads in either decibels or units of force.

Assistive listening devices (ALDs) Adjunct hearing instruments to improve signal-to-noise ratio. They may include personal amplifiers, FM systems, TV sets, or telephone amplifiers.

Athetosis One of the three major categories of cerebral palsy, characterized by squirming or writhing movements.

Atresia Congenital closure of a normally open body orifice, such as the external auditory canal.

Attenuation The reduction of energy (e.g., sound).

Audiocoil The same as a *telecoil*; a recommended name change to reflect this circuit's increasingly wider use beyond the telephone.

Audiogram A graphic representation of audiometric findings showing hearing thresholds as a function of frequency.

Audiological rehabilitation Treatment of those with adventitious hearing loss to improve communication through hearing aids, hearing therapy, speechreading, and counseling. Audiological *habilitation* of children may also include speech and language therapy, auditory training, and manual communication. Also known as aural rehabilitation.

Audiometer (pure-tone) A device for determining the thresholds of hearing. Pure tones at various frequencies are generated,

and their levels are increased and decreased until thresholds are found. Outputs may include earphones for air-conduction testing, a bone-conduction vibrator for bone-conduction testing, and one or more loudspeakers for sound-field testing.

Audiometric Weber test An extension of the tuning-fork Weber test. The bone-conduction vibrator of the audiometer is applied to the forehead of a patient, and tones are presented above threshold. The patient is directed to respond by stating whether the tone was heard in the right ear, the left ear, or the midline.

Auditory Reference to the sense of hearing.

Auditory brainstem response (ABR) The seven wavelets that appear within 10 milliseconds after signal presentation.

Auditory event-related potentials (ERP) AEPs that occur after latencies of about 60 milliseconds, with the largest positive wave at about 300 milliseconds. The earliest AEP requiring active participation by subjects to generate the response.

Auditory-evoked potentials (AEPs) The use of summing or averaging computers to observe the very small electrical responses to sound from the cochlea, brainstem, and cortex.

Auditory late responses (ALR) Those auditory-evoked potentials evident after about 60 milliseconds, usually of larger amplitude than the earlier responses. Pure tones may be used as stimuli, and frequency-specific information may be available.

Auditory middle-latency response (AMLR) Responses that occur 10 to 50 milliseconds after signal onset and are thought to arise from the upper brainstem.

Auditory nerve The VIIIth cranial nerve, which comprises auditory and vestibular branches, passing from the inner ear to the brainstem.

Auditory neuropathy spectrum disorder (ANSD) Formerly referred to as auditory neuropathy/auditory dys-synchrony (AN/ADys), this disorder presents as a mild to moderate sensory/neural hearing loss with speech-recognition difficulties disproportionate to degree of loss. In contrast to acoustic neuroma, there is an unexpected absence of ABR waveforms and a normal MRI.

Auditory placode A thickened plate near the hindbrain in the human embryo that develops into the inner ear.

Auditory processing disorders (APD) Difficulty in the development of language and other communication skills associated with disorders of the auditory centers in the brain.

Auditory radiations A bundle of nerve fibers passing from the medial geniculate body to the temporal gyri of the cerebral cortex.

Auditory training The training of the patient with a hearing loss in the optimum use of residual hearing.

Auditory steady-state response (ASSR) An auditory evoked potential for providing reliable frequency-specific threshold predictions in a clinically efficient time frame when behavioral thresholds cannot be obtained.

Aural rehabilitation Treatment to improve communication ability of those with hearing loss acquired after the development of spoken language.

Auricle The cartilaginous appendage of the external ear.

Auropalpebral reflex (APR) Contraction of the ring muscles of the eyes in response to a sudden, unexpected sound.

Autism A condition of withdrawal and introspection manifested by asocial behavior.

Autoimmune inner-ear disease (AIED) An inflammatory condition that arises when the body's immune system attacks the cells of the inner ear. The result may be a bilateral fluctuating and progressive sensory/neural hearing loss, associated with tinnitus, aural fullness, and vertigo.

Automatic gain control A special circuit within a hearing aid that prevents sounds from being overamplified for the impaired ear.

Autophony A condition produced by some middle-ear or eustachian tube abnormalities, in which individuals' voices seem louder than normal to themselves.

Autosomal dominant The capacity of a gene to express itself when carried by only one of a pair of homologous chromosomes.

Autosomal recessive The inability of a gene to express a trait unless it is carried by both members of a pair of homologous chromosomes.

Autosome Any chromosome other than a sex chromosome. There are 22 pairs in humans.

Axon The efferent portion of a neuron.

Barotrauma Damage to the ear by sudden changes in pressure, as in flying or diving.

Basilar membrane A membrane extending the entire length of the cochlea, separating the scala tympani from the scala media and supporting the organ of Corti.

Beats Periodic variations of the amplitude of a tone when a second tone of slightly different frequency is produced simultaneously.

Behavioral observation audiometry (BOA) Observation of changes in the activity state of an infant in response to sound.

Békésy audiometry Automatic audiometry wherein patients track their own auditory thresholds for both pulsed and continuous pure tones by depressing a switch when the tone becomes audible and releasing it when the tone is inaudible. Results are traced on a special audiogram blank. This test is no longer popular.

Bel A unit for expressing ratios of sound pressures in base 10 logarithms.

Bell's palsy Paralysis of the peripheral branch of the facial (VIIth cranial) nerve.

BiCROS hearing aid A modification of the CROS hearing aid (see *CROS*) in which there is one microphone on each side of the head, delivering signals to the better-hearing ear when one ear is unaidable.

Binaural Listening with both ears to either the same or different stimuli.

Bing test A tuning-fork test that utilizes the occlusion effect to test for the presence or absence of conductive hearing loss.

Bone conduction The course of sounds that are conducted to the inner ear by way of the bones of the skull.

Brownian motion The constant random colliding movement of molecules in a medium.

Calibration The electroacoustic or psychoacoustic determination that an audiometer is performing properly in terms of its acoustic output, attenuator linearity, frequency accuracy, harmonic distortion, and so on.

California Consonant Test A closed-message word-recognition test, with the emphasis on unvoiced consonants to tax the abilities of patients with high-frequency hearing losses.

Caloric test Irrigation of the external auditory canal with warm or cold water to stimulate the vestibular labyrinth. In normal patients the result is nystagmus with some sensation of vertigo.

Cancellation The reduction of the amplitude of a sound wave to zero. This results when two tones of the same frequency and amplitude are introduced 180 degrees out of phase.

Carhart notch An artifact in the bone-conduction audiograms of patients with otosclerosis making it appear that their sensorineural sensitivity is slightly poorer than it truly is. It is most evident at 2000 Hz and often disappears following corrective surgery.

Carotid artery The main large artery on either side of the neck. It passes beneath the anterior wall of the middle ear.

Carrier A phenotypically normal individual, whose body contains a recessive gene for an abnormal trait, along with its normal allele.

Carrier phrase A phrase, such as "Say the word . . ." or "You will say . . .," that precedes the stimulus word during speech audiometry. It is designed to prepare the patient for the test word and to assist the clinician (if monitored live voice is used) in controlling the input loudness of the test word.

Cell body The central portion of a nerve cell.

Central auditory processing disorder (CAPD) Impairment of the central auditory nervous system interfering with decoding of acoustic signals, including difficulties in sound localization and speech discrimination in noise. This term is often replaced by the less anatomically, more operationally defined term *auditory processing disorder*.

Central masking The shift in the auditory threshold of a tone produced by a noise in the opposite ear when the level of the noise is not sufficient to cause peripheral masking by cross-conduction.

Cerebellopontine angle (CPA) That area at the base of the brain at the junction of the cerebellum, medulla, and pons.

Cerebellum The lower part of the brain above the medulla and the pons and behind the brainstem. It is the seat of posture and integrated movements.

Cerebral palsy A motor disorder produced by damage to the brain; it usually occurs prenatally, perinatally, or in early infant life.

Cerebrovascular accident (CVA) A clot or hemorrhage of one of the arteries within the cerebrum; a stroke.

Cerumen Earwax.

Cerumenolytic A chemical substance (such as carbamide peroxide and glycerin) that is used to soften cerumen prior to removal.

CHARGE syndrome A congenital condition involving a number of body organs and virtually every part of the auditory system.

Cholesteatoma A tumor, usually occurring in the middle ear and mastoid, that combines fats and epithelium from outside the middle-ear space.

Chorda tympani nerve A branch of the facial (VIIth cranial) nerve that passes through the middle ear. It conveys information about taste from the anterior two-thirds of one side of the tongue.

Chromosome A structure in every animal cell nucleus that bears the genetic information.

Chronic A condition characterized by long duration.

Cilia Eyelash-like projections of some cells that beat rhythmically to move certain substances over their surfaces.

Clinical decision analysis (CDA) Procedures by which tests can be assessed in terms of their sensitivity, specificity, efficiency, and predictive value.

Cochlea A cavity in the inner ear resembling a snail shell and responsible for converting sound waves into an electrochemical signal that can be sent to the brain for interpretation.

Cochlear duct *See Scala media.*

Cochlear implant A coil and series of electrodes surgically placed in the mastoid and inner ear. It is designed to provide sound to a patient with a profound hearing loss through a processor and external coil.

Cochlear microphonic (CM) The measurable electrical response of the hair cells of the cochlea.

Cold running speech Rapidly delivered speech, either prerecorded or by monitored live voice, in which the output is monotonous and the peaks of the words strike zero on the VU meter.

Commissure Nerve fibers connecting similar structures on both sides of the brain.

Complex wave A sound wave made up of a number of different sinusoids, each with a different frequency.

Compliance The inverse of stiffness.

Component A pure-tone constituent of a complex wave.

Compression (1) That portion of a sound wave where the molecules of the medium are compressed together; also called condensation. (2) A decrease in pressure. In a hearing aid, a method of limiting the amplification of louder sounds relative to weaker sounds.

Computed tomography (CT) A procedure for imaging the inside of the body by representing portions of it as a series of sections. The many pictures taken are resolved by computer.

Computerized audiometry The process of testing human hearing sensitivity by having computers programmed to present the stimuli and interpret the threshold results.

Computerized dynamic posturography (CDP) A quantitative assessment of balance function for postural stability, performed by a computer-based moving platform and motion transducers.

Conditioned orientation reflex (COR) A technique for testing young children in the sound field by having them look in the direction of a sound source in search of a flashing light.

Conductive hearing loss The loss of sound sensitivity produced by abnormalities of the outer ear and/or middle ear.

Condyle The rounded projection, or process, of a bone. The condyle of the mandible comes to rest in a fossa (a hollowed or depressed area) just below the osseocartilaginous junction of the external auditory canal.

Connected Speech Test (CST) A procedure by which the intelligibility of speech passages is measured on a sentence-by-sentence basis in the presence of a related background babble.

Consonant-nucleus-consonant (CNC) words Monosyllabic words used in testing word recognition. Each word has three phonemes; the initial and final phonemes are consonants, and the middle phoneme is a vowel or diphthong.

CON-SOT-LOT A test for erroneous hearing loss using a standard audiometer both ascending and descending from below and above the patient's threshold. The tones may be continuously on, pulsed on and off at the same rate, or on for only 20% of the time per pulse.

Conversion disorder *See Psychogenic hearing loss.*

Conversion neurosis A Freudian concept by which emotional disorders become transferred into physical manifestations (e.g., hearing loss or blindness).

Corti's arch A series of arches made up of the rods of Corti in the cochlear duct.

Cosine wave A sound wave representing simple harmonic motion that begins at 90 degrees.

Critical band A portion of a continuous band of noise surrounding a pure tone. When the sound-pressure level of this narrow band is the same as the sound-pressure level of the tone, the tone is barely perceptible.

CROS (contralateral routing of offside signals) A hearing aid originally developed for patients with unilateral hearing losses. The microphone is mounted on the side of the poorer ear, and the signal is routed to the better ear and presented by an "open" earmold.

Cross hearing The reception of a sound signal during a hearing test (either by air conduction or bone conduction) at the ear opposite the ear under test.

Crura Legs, as of the stapes.

Crus Singular of crura.

Cued speech A system of handshapes or "cues" positioned near the mouth devised to augment speechreading by differentiating similar visual patterns of speech.

Cycle The complete sequence of events of a single sine wave through 360 degrees.

Cytomegalovirus (CMV) A common virus that is a member of the herpes family of viruses and can cause congenital hearing loss when contracted by a pregnant woman.

Damage-risk criteria The maximum safe allowable noise levels for different bandwidths.

Damping Progressive diminution in the amplitude of a vibrating body. Systems are said to be heavily damped when the amplitude decays rapidly, lightly damped when the amplitude decays slowly, and critically damped if all vibration ceases before the completion of one cycle.

Decibel (dB) A unit for expressing the ratio between two sound pressures or two sound powers; one-tenth of a Bel.

Decruitment The less-than-normal growth in loudness of a signal as the intensity is increased. Also called subtractive hearing loss, it is suggestive of a loss of nerve units.

Decussation A crossing over, as of nerve fibers connecting both sides of the brain.

Delayed auditory feedback (DAF) The delay in time between a subject's creation of a sound (e.g., speech) and his or her hearing of that sound.

Dementia The impairment of cognitive and intellectual functions. It is usually progressive and age-related and characterized by disorientation, impaired memory, judgment, and intellect.

Dendrite The branched portion of a neuron that carries the nerve impulse to the cell body.

Dichotic Stimulation of both ears by different stimuli. This is usually accomplished with earphones and two channels of a CD or tape player.

Dichotic digits test A test for central auditory disorders performed by presenting two pairs of digits simultaneously to both ears.

Difference tone The perceived pitch of a tone resulting from the simultaneous presentation of two tones of different frequencies. The tone perceived has a frequency equal to the difference in hertz between the other two tones.

Digital hearing aid An amplification system in which the input signal is stored, as by a computer, as sets of binary digits that represent the frequency, intensity, and temporal patterns of the input acoustical signal.

Diotic Stimulation of both ears with stimuli that are approximately identical, as through a stethoscope.

Diplacusis binauralis Hearing a tone of a single frequency as different pitches in the two ears.

Diplacusis monauralis Hearing a single frequency in one ear as a chord or noise.

Distortion In a hearing aid, the result of an inexact copy of the input signal by the output signal. Distortion is usually caused by the microphone, speaker, and/or amplifier.

Distortional bone conduction The response to a sound stimulus evoked when the skull is deformed by a bone-conduction vibrator, distorting the cochlea and giving rise to electrochemical activity within the cochlea.

Distortion-product otoacoustic emission (DPOAE) The emission of a sound from the cochlea, measured in the external auditory canal, which is the result of inner-ear distortion generated when two tones of different frequencies are introduced to the ear.

DNA Deoxyribonucleic acid, the fundamental molecular material that carries the genetic code.

Doerfler-Stewart test A binaural test for nonorganic hearing loss using spondaic words and a masking noise.

Dorsal cochlear nucleus The smaller of two cochlear nuclei on each side of the brain; it receives fibers from the cochlea on the ipsilateral side.

Down syndrome Sometimes called "trisomy 21 syndrome," Down disorder is characterized by mental retardation; a small, slightly flattened skull; low-set ears; abnormal digits; and other unusual facial and body characteristics.

Ductus reuniens A tube connecting the saccule with the scala media that carries endolymph to the cochlea.

Dynamic range (DR) for speech See *Range of comfortable loudness*.

Dyne (d) A unit of force just sufficient to accelerate a mass of 1 gram by 1 cm/sec².

Dysacusis Distortion of an auditory signal that is associated with loss of auditory sensitivity. Evidenced by poor word recognition.

Dysinhibition Bizarre behavior patterns often associated with brain-damaged individuals.

Eardrum membrane The vibrating membrane that separates the outer ear from the middle ear; more correctly called the *tympanic membrane*.

Ectoderm The outermost of the three primary embryonic germ layers.

Effective masking (EM) The minimum amount of noise required just to mask out a signal (under the same earphone) at a given hearing level. For example, 40 dB EM will just mask out a 40 dB HL signal.

Efferent Nerves that carry impulses from the brain toward the periphery.

Efficiency The percentage of time that a test correctly identifies a site of lesion and correctly eliminates an anatomical area as the site of lesion.

Elasticity The ability of a mass to return to its natural shape.

Electrocochleography (ECoG) Response to sound in the form of electrical potentials that occur within the first few milliseconds after signal presentation. The responses that arise from the cochlea are small in amplitude and must be summed on a computer after a number of presentations of clicks or tone pips.

Electroencephalograph (EEG) A tracing showing changes in the electrical potentials in the brain.

Electronic voltmeter A device for measuring differences in decibels and voltages.

Electronystagmograph (ENG) A device used to monitor electrically the amount of nystagmus occurring spontaneously or from vestibular stimulation.

Endogenous Produced or originating within the organism.

Endolymph The fluid contained within the membranous labyrinth of the inner ear in both the auditory and vestibular portions.

Entoderm The innermost of the three primary embryonic germ layers.

Epitympanic recess That part of the middle ear above the upper level of the tympanic membrane. Also called the attic of the middle ear.

Equivalent input noise level The inherent noise level within a hearing aid with the input signal turned off and the hearing aid set at the reference-test-gain level.

Equivalent volume A method of approximating the compliance component of impedance; the volume (in cm³) with a physical property equivalent to a similar property of the middle ear.

Erg (e) A unit of work. One erg results when 1 dyne force displaces an object by 1 centimeter.

Erroneous hearing loss The falsification or exaggeration of hearing ability for some conscious or unconscious reason.

Eustachian tube The channel connecting the middle ear with the nasopharynx on each side. It is lined with mucous membrane and is sometimes called the auditory tube.

Evidence-based practice The conscious and clear use of the current best evidence, practitioner experience, and patient concerns and expectations in making decisions toward individualized patient care.

Evoked otoacoustic emission (EOAE) A measurable echo produced by the cochlea in response to signals presented to the ear.

Exogenous Produced or originating outside the organism.

Exostoses Projections from the surfaces of bone, as the external auditory canal, that are usually covered with cartilage.

Exponent A logarithm, or power, to which a number may be raised.

External auditory canal (EAC) The channel in the external ear from the concha of the auricle to the tympanic membrane.

External otitis Infection of the outer ear. Also called otitis externa.

Extra-axial Outside the brainstem.

False or exaggerated hearing loss See *Erroneous hearing loss*.

Facial nerve The VIIth cranial nerve, which innervates the muscles of the face and the stapedius muscle.

Factitious disorder See *Erroneous hearing loss*.

Fallopian canal A bony channel, on the medial wall of the middle ear, through which the facial nerve passes. It is covered with a mucous membrane.

False negative response The failure of patients to respond during a hearing test when they have, in fact, heard the stimulus.

False positive response Response from a subject when no stimulus has been presented, or the stimulus is below threshold.

Fascia Layers of tissue that form the sheaths of muscles.

Fenestration An early operation designed to correct hearing loss from otosclerosis. A new window was created in the lateral balance canal of the inner ear, and the ossicular chain was bypassed.

Fistula An abnormal opening, as by incomplete closure of a wound, that allows fluid to leak out.

Footplate The base of the stapes, which occupies the oval window.

Force The impetus required to institute or alter the velocity of a body.

Forced vibration The vibration of a mass controlled and maintained by an external impetus.

Formant A peak of energy in the spectrum of a vowel sound.

Fourier analysis The mathematical breakdown of any complex wave into its component parts, consisting of simple sinusoids of different frequencies.

Free field An acoustic environment with no reverberating surfaces.

Free vibration The vibration of a mass independent of any external force.

Frequency The number of complete oscillations of a vibrating body per unit of time. In acoustics the unit of measurements is cycles per second (cps) or hertz (Hz).

Frequency distortion An inexact reproduction of the frequencies in a sound wave.

Frequency response The frequency range of amplification (as in a hearing aid), expressed in hertz, from the lowest to the highest frequency amplified.

Frequency-based theories of hearing The explanation for pitch perception based on the frequency of neural impulses in the auditory nerve.

Functional gain The difference in decibels between unaided and aided thresholds of hearing.

Functional hearing loss See *Erroneous hearing loss*.

Fundamental frequency The lowest frequency of vibration in a complex wave.

Furunculosis Infection of hair follicles, as in the external auditory canal.

Gamma Knife An approach to removal of harmful tissue, such as tumors, by using gamma rays. These consist of penetrating electromagnetic radiation, which have shorter wavelengths than X-rays and arrest the growth of tumors without necessarily destroying them.

Gene The unit of heredity, composed of a sequence of DNA, that is located in a specific position on a chromosome.

Genotype The genetic constitution of an individual.

Ground electrode The third electrode used in testing auditory evoked potentials to ground subjects so that their bodies cannot serve as an antenna.

Harmonic Any whole-number multiple of the fundamental frequency of a complex wave. The fundamental frequency equals the first harmonic.

Harmonic distortion The distortion created when harmonic frequencies are generated in an amplification system; usually expressed in percentage of distortion.

Hearing Aid Industry Conference (HAIC) An organization of hearing aid manufacturers that provides standardization of measurement and reporting on hearing aid performance data.

Hearing assistance technologies (HAT) See *Assistive listening devices*.

Hearing disability An inability to perform socially useful functions due to hearing loss. A given disability may, or may not, present a handicap.

Hearing handicap The ways in which a hearing loss has a frustrating effect on individual roles or goals.

Hearing impairment Abnormality of structure or function that is physiological, psychological, or anatomical.

Hearing level (HL) The number of decibels above an average normal threshold for a given signal. The hearing-level dial of an audiometer is calibrated in dB HL.

Hearing loss Any loss of sound sensitivity, partial or complete, produced by an abnormality anywhere in the auditory system.

Hearing therapy An instruction, usually offered in groups, to enhance recognition of, and intervention for, those variables within the environment, or poor speaker or listener habits, that impede successful communication.

Helicotrema A passage at the apical end of the cochlea connecting the scala vestibuli with the scala tympani.

Hemotympanum Bleeding in the middle ear.

Hereditodegenerative hearing loss Hearing loss that has its onset after birth but is nonetheless hereditary.

Hertz (Hz) Cycles per second (cps).

Heschl's gyrus See *Superior temporal gyrus*.

Heterozygous Possessing different genes at a specific site between paired chromosomes.

High-frequency average (HFA) An ANSI hearing aid specification expressed as the average SPL at 1000, 1600, and 2500 Hz.

High-risk registry A set of criteria designed to help identify neonates whose probability of hearing loss is greater than normal.

Homozygous Possessing identical genes at a specific site between paired chromosomes.

Human immunodeficiency virus (HIV) A virus transmitted through body fluids that first appeared in the United States in the early 1980s. The virus affects the immune system and creates the possibilities of conductive, sensory, and neural hearing loss.

Hypacusis Loss of hearing sensitivity.

Hyperacusis A collapse of loudness tolerance with or without accompanying hearing loss.

Hysterical deafness An older term for *psychogenic hearing loss*.

Immittance A term used to describe measurements made in the plane of the tympanic membrane.

Impedance The opposition to sound-wave transmission. It comprises frictional resistance, mass, and stiffness and is influenced by frequency.

Incus The second bone in the ossicular chain, connecting the malleus to the stapes. It is named for its resemblance to an anvil.

Individual educational plan (IEP) An annually updated, federally mandated plan for the education of children with handicaps.

Individual family service plan (IFSP) An annually updated, federally mandated plan for early intervention services for infants and toddlers with special needs and their families.

Induction loop A continuous wire surrounding a room or listening area that radiates a magnetic field as electrical energy that is conducted through the wire from a microphone. The electromagnetic current flow from the wire is induced in the induction coil of a hearing aid (i.e., telecoil/audiocoil).

Inertial bone conduction Stimulation of the cochlea caused by lag of the chain of middle-ear bones, or inner-ear fluids, when the skull is deformed, resulting in movement of the stapes in and out of the oval window.

Inferior colliculus One of the central auditory pathways, found in the posterior portion of the midbrain.

Initial masking (IM) The lowest level of effective masking presented to the nontest ear. For air-conduction tests, this level is equal to the threshold of the masked ear; for bone-conduction tests the IM is equal to the air-conduction threshold of the masked ear plus the occlusion effect at each frequency.

Inner ear That portion of the hearing mechanism, buried in the bones of the skull, that converts mechanical energy into electrochemical energy for transmission to the brain.

Insertion gain The decibel difference between unaided and aided conditions as measured through a probe-tube microphone system. Commonly referred to as real ear insertion gain (REIG).

Insertion loss The additional loss of hearing created by placing a hearing aid, turned off, within the ear.

Insular Related to the insula, the central lobe of the cerebral hemisphere.

Integrated circuit An inseparable unification of several transistors and resistors on a small piece of silicon maintaining an electrical isolation of the circuit components.

Intensity The amount of sound energy per unit of area.

Intensity level (IL) An expression of the power of a sound per unit of area. The reference level in decibels is 10^{-12} watt/m², or 10^{-16} watt/cm².

Interaural attenuation (IA) The loss of energy of a sound presented by either air conduction or bone conduction as it travels from the test ear to the nontest ear; the number of decibels lost in cross hearing.

Internal auditory canal A channel from the inner ear to the brainstem allowing passage of the auditory and vestibular branches of the VIIIth nerve, the VIIth nerve, and the internal auditory artery.

International Organization for Standardization (ISO) A worldwide consortium of 148 nations, based in Geneva, Switzerland, whose mandate is to oversee and set guidelines for literally thousands of devices, including audiometers. See *ISO*.

Intra-aural muscle reflex The contraction of the stapedius muscles produced by introduction of an intense sound to one ear. The reflex is a bilateral phenomenon.

Intra-axial Inside the brainstem.

Intraoperative monitoring The use of auditory evoked potentials, such as ECoG and ABR, for monitoring some of the electrophysiological states of the patient during neurosurgery.

Inverse square law The intensity of a sound decreases as a function of the square of the distance from the source.

ISO An internationally accepted abbreviation derived from the Greek *isos*, meaning equal. This single abbreviation is used to represent similar organizations in all languages. See *International Organization for Standardization*.

Joule (J) The work obtained when a force of one Newton displaces an object one meter (one J is equal to 10 million ergs).

Jugular bulb The bulbous protrusion of the jugular vein in the floor of the middle ear.

Kernicterus Deposits of bile pigment in the central nervous system, especially the basal ganglia. It is associated with erythroblastosis and the Rh factor.

Kinetic energy The energy of a mass that results from its motion.

Labyrinth The system of interconnecting canals of the inner ear, composed of the bony labyrinth (filled with perilymph), that contains the membranous labyrinth (filled with endolymph).

Labyrinthitis Inflammation of the labyrinth, resulting in hearing loss and vertigo.

Latency The time delay between the presentation of a stimulus and the measured physiological response to that stimulus.

Lateral lemniscus That portion of the auditory pathway running from the cochlear nuclei to the inferior colliculus and medial geniculate body.

Lateralization The impression that a sound introduced directly to the ears is heard in the right ear, the left ear, or the midline.

Lipreading See *Speechreading*.

Localization The ability of an animal to determine the specific location of a sound source.

Logarithm The exponent that tells the power to which a number is raised; the number of times that a number (the base) is multiplied by itself.

Lombard test A test for nonorganic hearing loss based on the fact that speakers will increase the loudness of their speech when a loud noise interferes with their normal auditory monitoring.

Lombard voice reflex The normal elevation of vocal intensity when the speaker listens to a loud noise.

Longitudinal wave A wave in which the particles of the medium move along the same axis as the wave.

Loudness The subjective impression of the power of a sound. The unit of measurement is the sone.

Loudness discomfort level See *Uncomfortable loudness level*.

Loudness level The intensity above the reference level for a 1000 Hz tone that is subjectively equal in loudness. The unit of measurement is the phon.

Magnetic resonance imaging (MRI) A system of visualizing the inside of the body without the use of X-rays. The body is placed in a magnetic field and bombarded with radio waves, some of which are re-emitted and resolved by computer, which allows for viewing soft tissues and various abnormalities.

Mainstreaming Integrating children with hearing impairments (or other disabilities) into the "least restrictive" educational setting. This often implies placement in a regular school classroom with special educational assistance, where necessary.

Malingering The conscious, willful, and deliberate act of feigning or exaggerating a disability (such as hearing loss) for personal gain or exemption.

Malleus The first and largest bone in the ossicular chain of the middle ear, connected to the tympanic membrane and the incus; so named because of its resemblance to a hammer.

Manually-Coded English Any communication system that expresses spoken English through a variety of hand signs and/or fingerspelling.

Manubrium A process of the malleus embedded in the fibrous layer of the tympanic membrane.

Masking The process by which the threshold of a sound is elevated by the simultaneous introduction of another sound.

Masking-level difference (MLD) The binaural threshold for a pure tone is lower when a binaural noise is 180 degrees out of phase than when the noise is in phase between the two ears.

Mass The quantity of a body as measured in terms of its relationship to inertia. The weight of a body divided by its acceleration due to gravity.

Mass reactance The quantity that results from the formula $2\pi fM$ (two times pi times frequency times mass).

Mastoid process A protrusion of the temporal bone, behind the outer ear, one portion of which is pneumatized (filled with air cells).

Mastoidectomy An operation to remove infected cells of the mastoid. Mastoidectomies are termed as simple, radical, and modified radical, depending on the extent of surgery.

Mastoiditis Infection of the mastoid.

Maximum masking The highest level of noise that can be presented to one ear through an earphone before the noise crosses the skull and shifts the threshold of the opposite ear.

Meatus A passage, such as the external auditory canal.

Medial geniculate body The final subcortical auditory relay station, found in the thalamus on each side of the brain.

Medulla oblongata The lowest portion of the brain, connecting the pons with the spinal cord.

Mel A unit of pitch measurement. One thousand mels is the pitch of a 1000 Hz tone at 40 dB SL, 2000 mels is the subjective pitch exactly double 1000 mels, and so on.

Ménière's disease A disease of the inner ear whose symptoms include tinnitus, vertigo, and hearing loss (usually fluctuating and unilateral).

Meningitis Inflammation of the meninges, the three protective coverings of the brain and spinal cord.

Meniscus The curved surface of a column of fluid. A meniscus is sometimes seen through the tympanic membrane when fluids are present in the middle ear.

Mesenchyme A network of embryonic connective tissue in the mesoderm that forms the connective tissue, blood vessels, and lymph vessels of the body.

Mesoderm The middlemost of the three primary embryonic germ layers, lying between the ectoderm and the entoderm.

Metacognitive training Development of strategies to help a person to think about the process of thought in order to strengthen self-regulation of spoken language processing.

Metalinguistic training Learning to think and communicate about language to aid in processing. Skill development may include use of mnemonics, rehearsal, paraphrasing, summarizing, and segmentation.

Microbar (μ bar) A pressure equal to one-millionth of standard atmospheric pressure (1 bar equals 1 dyne/cm²).

Microtia A congenitally abnormally small external ear.

Middle ear An air-filled cavity containing a chain of three tiny bones whose function is to carry energy from the outer ear to the inner ear.

Middle-ear cleft The space made up of the middle ear and the eustachian tube.

Minimal auditory deficiency syndrome (MADS) Changes in the size of neurons in the central auditory nervous system caused by conductive hearing loss in early life. The result is difficulty in language learning.

Minimum contralateral interference level On the Stenger test, the lowest intensity of a signal presented to the poorer ear that causes the patient to stop responding to the signal that is above threshold in the better ear.

Minimum response level (MRL) The lowest level of response offered by a child to an acoustic stimulus. Depending on a variety

of circumstances, the signal responded to may be either barely audible or well above threshold.

Mismatch negativity (MMN) A small negative response evoked when subjects are instructed to attend to a set of stimuli in one ear while different signals are presented to the other ear.

Mixed hearing loss A sensory/neural hearing loss with superimposed conductive hearing loss. The air-conduction level shows the entire loss; the bone-conduction level, the sensory/neural portion; and the air-bone gap, the conductive portion.

Modiolus The central pillar of the cochlea.

Monaural Listening with one ear.

Monitored live voice (MLV) Introduction of a speech signal (as in speech audiometry) through a microphone. The loudness of the voice is monitored visually by means of a VU meter (sometimes displayed as a series of light-emitting diodes).

Moro reflex A sudden embracing movement of the arms and drawing up of the legs of infants and small children in response to sudden loud sounds.

Most comfortable loudness (MCL) The hearing level designated by a listener as the most comfortable listening level for speech.

Mucous membrane A form of epithelium found in many parts of the body, including the mouth, nose, paranasal sinuses, eustachian tube, and middle ear. Its cells contain fluid-producing glands.

Multifactorial genetic considerations Arising from the interaction of several genes and environmental factors.

Multiple sclerosis (MS) A chronic disease showing hardening or demyelination in different parts of the nervous system.

Myringitis Any inflammation of the tympanic membrane.

Myringoplasty Surgery for restoration or repair of the tympanic membrane.

Myringotomy Incision of the tympanic membrane.

Narrowband noise A restricted band of frequencies surrounding a particular frequency to be masked; usually obtained by band-pass filtering a broadband noise.

Nasopharynx The area where the back of the nose and the throat communicate.

Necrosis The death of living cells.

Neoplasm Any new or aberrant growth, as a tumor.

Neuritis Inflammation of a nerve with accompanying sensory or motor dysfunction.

Neurofibromatosis (NF) The presence of tumors on the skin or along peripheral nerves; also called von Recklinghausen disease.

Neurofibromatosis type 2 A hereditary disorder characterized by bilateral tumors along the cochleovestibular nerve; associated with hearing loss and other intracranial tumors.

Neuron A cell specialized as a conductor of nerve impulses.

Neurotransmission The manner in which neurons communicate with one another neurochemically.

Neurotransmitter A chemical substance that is released to bridge the gap between neurons so that neurotransmission can be facilitated.

Newton (N) The force required to give a one kilogram mass an acceleration of 1 m/sec² (one N equals 100,000 d).

Nonorganic hearing loss See *Erroneous hearing loss*.

Northwestern University Children's Perception of Speech (NUCHIPS) test A picture-identification test for measuring the word-recognition abilities of small children.

Nystagmus An oscillatory motion of the eyes.

Objective audiometry Procedures for testing the hearing function that do not require behavioral responses.

Obscure auditory dysfunction (OAD) Often difficult-to-diagnose auditory processing disorders.

Occlusion effect (OE) The impression of increased loudness of a bone-conducted tone when the outer ear is tightly covered or occluded.

Octave The difference between two tones separated by a frequency ratio of 2:1.

Ohm (Ω) A unit of impedance.

Operant conditioning audiometry (OCA) The use of tangible reinforcement, such as edible items, to condition difficult-to-test patients for pure-tone audiometry.

Organ of Corti The end organ of hearing found within the scala media of the cochlea.

Oscillation The back-and-forth movement of a vibrating body.

Osseocartilaginous junction The union between the bony and cartilaginous portions of the external auditory canal.

Osseotympanic bone conduction The contribution to hearing by bone conduction created when the vibrating skull sets the air in the external ear canal into vibration, causing sound waves to pass down the canal, impinging on the eardrum membrane, and being conducted through the middle ear to the cochlea.

Ossicles The chain of three tiny bones found in each middle ear (malleus, incus, and stapes).

Osteitis Inflammation of bone marked by tenderness, enlargement, and pain.

Osteomyelitis Inflammation of bone caused by a purulent infection.

Otalgia Pain in the ear.

Otitis media Any infection of the middle ear.

Otoacoustic emissions (OAEs) Sounds emanating from the cochlea that can be detected in the external auditory canal with probe-tube microphones.

Otocyst The auditory vesicle (sac) of the human embryo.

Otology Subspecialty of medicine devoted to the diagnosis and treatment of diseases of the ear.

Otomycosis Fungal infection of the external ear.

Otoplasty Any plastic surgery of the outer ear.

Otorrhea Any discharge from the external auditory canal or from the middle ear.

Otosclerosis The laying down of new bone in the middle ear, usually around the footplate of the stapes. When it interferes with stapedial vibration, it produces a progressive conductive hearing loss.

Otoscope A special flashlight device with a funnel-like speculum on the end, designed to observe the tympanic membrane.

Otospongiosis See *Otosclerosis*.

Ototoxic Poisonous to the ear.

Outer ear The outermost portion of the hearing mechanism, filled with air, whose primary function is to carry sounds to the middle ear.

Output sound-pressure level (OSPL) The newer term for maximum power output of a hearing aid; the highest sound-pressure level to leave the receiver of a hearing aid, regardless of the input level.

Oval window A tiny, oval-shaped aperture beneath the footplate of the stapes. The oval window separates the middle ear from the inner ear.

Overmasking (OM) Occurs when a masking noise presented to the nontest ear is of sufficient intensity to shift the threshold in the test ear beyond its true value. In overmasking, the masking noise crosses from the masked ear to the test ear by bone conduction.

Overtone Any whole-number multiple of the fundamental frequency of a complex wave. It differs from the harmonic only in the numbering used (e.g., the first overtone is equal to the second harmonic).

Paracusis willisii A condition found among patients with conductive hearing loss in which they understand speech better in noisy than in quiet surroundings.

Parietal lobe The division of each side of the cerebral cortex between the frontal and occipital lobes.

Pars flaccida The loose folds of epithelium of the tympanic membrane above the malleus; also called Shrapnell's membrane.

Pars tensa All of the remaining (taut) portion of the tympanic membrane besides the pars flaccida.

Pascal (Pa) A unit of pressure equal to 1 N/m².

PB Max The highest word-recognition score obtained with phonetically balanced (PB) word lists on a performance-intensity function, regardless of level.

Performance-intensity function for PB word lists (PI-PB) A graph showing the percentage of correctly identified word-recognition materials as a function of intensity. The graph usually shows the word-recognition score on the ordinate and the sensation level on the abscissa.

Perilymph The fluid contained in both the auditory and vestibular portions of the bony labyrinth of the inner ear.

Period The duration (in seconds) of one cycle of vibration. The period is the reciprocal of frequency (e.g., the period of a 1000 Hz tone is 1/1000 second).

Periodic sound A complex sound that repeats over time.

Permanent threshold shift (PTS) Permanent sensory/neural loss of hearing, usually associated with exposure to intense noise.

Perseveration Persistent repetition of an activity.

Pharyngeal arches Paired embryonic arches that modify, in humans, into structures of the ear and neck. In fish they modify into gills.

Phase The relationship in time between two or more waves.

Phenotype The observable makeup of an individual, that is determined by genetic or a combination of genetic and environmental factors.

Phon The unit of loudness level. It corresponds to the loudness of a signal at other frequencies equal to the intensity of a 1000 Hz tone.

Phonemic regression A slowness in auditory comprehension associated with advanced age.

Phonetically balanced (PB) word lists Lists of monosyllabic words used for determining word-recognition scores. Theoretically, each list contains the same distribution of phonemes that occurs in connected English discourse.

Physical-volume test (PVT) A high sound intensity, suggesting a large volume of air (greater than 5 cm³) may be observed on c₁ during immittance measures. This indicates that a patent P.E. tube or tympanic membrane perforation is present.

Picture Identification Task (PIT) A word-recognition test using pictures of rhyming CNC words.

Pinna The auricle of the external ear.

Pinnaplasty A cosmetic operation designed to improve the appearance of the pinna.

Pitch The subjective impression of the highness or lowness of a sound; the psychological correlate of frequency.

Place theory of hearing The explanation for pitch perception based on a precise place on the organ of Corti, which when stimulated results in the perception of a specific pitch.

Plasticity The ability of cells, such as those in the auditory centers of the brain, to become altered in order to conform to their immediate environment.

Plateau The theoretical point in clinical masking at which the level of noise in the nontest ear may be raised or lowered about 15 dB without affecting the threshold of the signal in the test ear; the levels between undermasking and overmasking at which the true threshold of the test ear may be seen.

Pneumatic mastoid The formation of air cavities in tissues, as in the temporal bones of the skull.

Politzerization Inflation of the middle ear via the eustachian tube by forcing air through the nose.

Pons A bridge of fibers and neurons that connect the two sides of the brain at its base.

Positron emission tomography (PET) A medical imaging procedure that can indicate changes in the brain with a minimum of patient exposure to radioactivity. It is useful in identifying biochemical changes in the brain.

Postlinguistic hearing loss Hearing loss acquired by children after they have developed some language skills.

Posttraumatic stress disorder (PTSD) Development of dramatic symptoms, including cognitive dysfunction, following a psychologically traumatic event.

Potential energy Energy resulting from a fixed and relative position, as a coiled spring.

Power The rate at which work is done. Units of measurement are watts or ergs/second.

Predictive value The percentage of all positive test results that are truly positive and the percentage of all negative test results that are truly negative.

Prelinguistic hearing loss Hearing loss that is either congenital or acquired before language skills have been developed.

Presbycusis Hearing loss associated with old age.

Pressure Force over an area of surface.

Pressure-equalizing (P.E.) tube A short tube or grommet placed through a myringotomy incision in a tympanic membrane to allow for middle-ear ventilation.

Prevalence The number of existing cases of a disease or condition within a population at any given time.

Probe-tube microphone A microphone used to provide electroacoustic measures of hearing aid performance as the instrument is worn. The test is performed by placing a thin silicone tube, which is connected to a microphone that is inserted into the external auditory canal.

Promontory A protrusion into the middle ear, at its labyrinthine wall, produced by the basal turn of the cochlea.

Pseudohypacusis See *Erroneous hearing loss*.

Psychogenic hearing loss An erroneous hearing loss possibly produced at the unconscious level, as by an anxiety state.

Psychophysical tuning curve (PTC) The measurable response in the cochlea to specific frequencies introduced into the ear.

Pure tone A tone of only one frequency (i.e., no harmonics).

Pure-tone average (PTA) The average of the hearing levels at frequencies 500, 1000, and 2000 Hz for each ear, as obtained on a pure-tone hearing test. Sometimes the pure-tone average is computed by averaging the two lowest thresholds obtained at 500, 1000, and 2000 Hz.

Purulent Related to the formation of pus.

Quality The sharpness of resonance of a sound system; the vividness or identifying characteristics of a sound; the subjective counterpart of spectrum; timbre.

Range of comfortable loudness (RCL) The difference, in decibels, between the threshold for speech and the point at which speech becomes uncomfortably loud. It is determined by subtracting the SRT from the UCL. Also called the dynamic range (DR) for speech.

Rapidly Alternating Speech Perception (RASP) test A test for central auditory disorders in which sentences are rapidly switched from the left ear to the right ear. Normal brainstem function is required for discrimination.

Rarefaction That portion of a sound wave where the molecules become less densely packed per unit of space.

Ratio The mathematical result of a quantity divided by another quantity of the same kind, often expressed as a fraction.

Reactance The contribution to total acoustic impedance provided by mass, stiffness, and frequency.

Recruitment A large increase in the perceived loudness of a signal produced by relatively small increases in intensity above threshold; symptomatic of some hearing losses produced by damage to the cochlea.

Reference test gain The acoustic gain of a hearing aid as measured in a hearing aid test box. The gain control of the aid is set to amplify an input signal of 60 dB SPL to a level 17 dB below the OSPL90 value. The average values at 1000, 1600, and 2500 Hz determine the reference test gain.

Reflex-activating stimulus (RAS) A pure tone or other acoustic signal of high intensity designed to cause the stapedial muscle to

contract. The RAS can be presented through the probe assembly of an immittance meter to observe an acoustic reflex in the ear that houses the probe tip (the ipsilateral reflex), or it can be presented via an earphone in the ear opposite the probe (the contralateral acoustic reflex).

Reissner's membrane A membrane extending the entire length of the cochlea, separating the scala media from the scala vestibuli.

Resistance The opposition to a force.

Resonance The ability of a mass to vibrate at a particular frequency with a minimum application of external force.

Resonance theory of hearing A 19th-century theory of pitch perception that suggested that the cochlea consisted of a series of resonating tubes, each tuned to a specific frequency.

Resonance-volley theory of hearing A combination of the place and frequency theories of hearing that suggests that nerve units in the auditory nerve fire in volleys, allowing pitch perception up to about 4000 Hz. Perception of pitch above 4000 Hz is determined by the point of greatest excitation on the basilar membrane.

Resonant frequency The frequency at which a mass vibrates with the least amount of external force; the natural frequency of vibration of a mass.

Retrocochlear Located behind the cochlea.

Reverberation A short-term echo, or the continuation of a sound in a closed area after the source has stopped vibrating, resulting from reflection and refraction of sound waves.

Rh factor Pertaining to the protein factor found on the surface of the red blood cells in most humans. Named for the Rhesus monkey, in which it was first observed.

Rinne test A tuning-fork test that compares hearing by air conduction with hearing by bone conduction.

Rotary chair testing A test of vestibular function using a chair that rotates with varying velocity in both clockwise and counterclockwise direction. During rotation electronystagmographic findings are recorded.

Round window A small, round aperture containing a thin but tough membrane. The round window separates the middle ear from the inner ear.

Saccule The smaller of the two sacs found in the membranous vestibular labyrinth; it contains an end organ of equilibrium.

Scala media The duct in the cochlea separating the scala vestibuli from the scala tympani. It is filled with endolymph and contains the organ of Corti.

Scala tympani The duct in the cochlea below the scala media, filled with perilymph.

Scala vestibuli The duct in the cochlea above the scala media, filled with perilymph.

Schwabach test A tuning-fork test that compares an individual's hearing by bone conduction with the hearing of an examiner (who is presumed to have normal hearing).

Schwartz sign A red glow seen through the tympanic membrane and produced by increased vascularity of the promontory in some cases of otosclerosis.

Screening Test for Auditory Processing Disorders (SCAN) A rapid test for central auditory processing disorders comprising

three subtests: filtered words, auditory figure ground, and dichotic listening.

Semicircular Canal Dehiscence Syndrome (SCDS) Frequently misdiagnosed as a peripheral vestibular disorder, SCDS symptoms of dizziness, vertigo, and disequilibrium are induced by intense sounds or change in middle-ear pressure.

Semicircular canals Three loops in the vestibular portion of the inner ear responsible for the sensation of turning.

Sensation level (SL) The number of decibels above the hearing threshold of a given subject for a given signal.

Sensitivity The percentage of time a test correctly identifies a site of lesion.

Sensitivity prediction from the acoustic reflex (SPAR) A test designed to identify the presence and approximate degree of sensory/neural hearing loss through comparison of acoustic reflex thresholds elicited with pure tones and with broadband noise.

Sensory/neural hearing loss Formerly called perceptive loss or nerve loss, this term refers to loss of hearing sensitivity produced by damage or alteration of the sensory mechanism of the cochlea or the neural structures that lie beyond.

Serous effusion The collection of fluid in the middle-ear space, with possible drainage into the external ear canal. Often called serous otitis media.

Short increment sensitivity index (SISI) A test designed to determine a patient's ability to detect small changes (1 dB) in intensity of a pure tone presented at 20 dB SL.

Shrapnell's membrane The pars flaccida of the tympanic membrane.

Signal-to-noise ratio (SNR) The difference, in decibels, between a signal (such as speech) and a noise presented to the same ear(s). When the speech has greater intensity than the noise, a positive sign is used; when the noise has greater intensity than the signal, a negative sign is used.

Sinusoidal or sine waves The waveform of a pure tone showing simple harmonic motion.

Site of lesion The precise area in the auditory system producing symptoms of abnormal auditory function.

Somatosensory Spatial orientation provided by proprioceptive input, as by the support the body receives on a surface.

Sone The unit of loudness measurement. One sone equals the loudness of a 1000 Hz tone at 40 dB SPL.

Sound-evoked muscle reflex A reflex believed to be generated from acoustical stimulation of the saccule. It is used in the diagnosis of vestibular disorders.

Sound-level meter A device designed for measurement of the intensity of sound waves in air. It consists of a microphone, an amplifier, a frequency-weighting circuit, and a meter calibrated in decibels with a reference of 20 μ Pa.

Sound-pressure level (SPL) An expression of the pressure of a sound. The reference level in decibels is 20 μ Pa.

Specificity The percentage of time a test correctly rejects an incorrect diagnosis.

Spectrum The sum of the components of a complex wave.

Speech conservation Therapy to maintain clear articulation when the auditory feedback for speech production has been hindered by postlinguistic hearing loss.

Speech-detection threshold (SDT) The hearing level at which a listener can just detect the presence of an ongoing speech signal and identify it as speech. Sometimes called the speech awareness threshold (SAT).

Speech-language pathology The study of speech, language, and voice disorders in children and adults for the purposes of diagnosis and treatment.

Speech Perception in Noise (SPIN) test A prerecorded sentence test with a voice babble recorded on the second channel of the same recording.

Speechreading The use of visual (primarily facial) cues to determine the words of a speaker.

Speech-recognition score (SRS) The percentage of correctly identified items on a speech-recognition test.

Speech-recognition threshold (SRT) The threshold of intelligibility of speech; the lowest intensity at which at least 50 percent of a list of spondee words can be identified correctly.

Speech spectrum The overall level and frequency composition of the energy of everyday conversational speech.

Spiral ligament The thickened outer portion of the periosteum of the cochlear duct that forms a spiral band and attaches to the basilar membrane.

Spondaic word (spondee) A two-syllable word pronounced with equal stress on both syllables.

Spontaneous otoacoustic emission (SOAE) A weak sound, emanating from the cochlea with no external stimulation, that travels through the middle ear and can be measured by a sensitive microphone placed in the external auditory canal.

Stacked ABR A composite auditory brainstem response reflecting activity from all frequency regions of the cochlea attained by aligning (in time) and adding the amplitudes of derived narrow-band ABRs obtained using a high-pass noise/subtraction technique. The result yields a measure more sensitive to identification of small acoustic neuromas.

Staggered Spondaic Word (SSW) test A test for central auditory disorders utilizing the dichotic listening task of two spondaic words so that the second syllable presented to one ear is heard simultaneously with the first syllable presented to the other ear.

Stapedectomy An operation designed to improve hearing in cases of otosclerosis by removing the affected stapes and replacing it with a prosthesis.

Stapedius muscle A tiny muscle, innervated by the facial nerve and connected to the stapes in the middle ear by the stapedius tendon. Both stapedius muscles normally contract, causing a change in the resting position of the tympanic membrane when either ear is stimulated by an intense sound.

Stapedotomy A small fenestra stapedectomy.

Stapes The third and smallest bone in the ossicular chain of the middle ear, connected to the incus and standing in the oval window; so named because of its resemblance to a stirrup.

Stapes mobilization An operation to improve hearing in cases of otosclerosis by breaking the stapes free of its fixation in the oval window and allowing normal vibration. It is no longer commonly performed.

Static acoustic compliance A measurement of the mobility of the tympanic membrane.

Stenger principle When two tones of the same frequency are presented to both ears simultaneously, only the louder one is perceived.

Stenger test A test for unilateral nonorganic hearing loss based on the Stenger principle.

Stenosis An abnormal narrowing, as of the external auditory canal.

Stereocilia A protoplasmic filament on the surface of a cell (e.g., a hair cell).

Sternocleidomastoid muscle A large muscle that runs from the mastoid process to the joint between the collarbones and the sternum at the base of the throat.

Stiffness The flexibility or pliancy of a mass. The inverse of compliance.

Stiffness reactance The quantity that results when the stiffness of a body is divided by $2\pi f$ (two times pi times frequency).

Stria vascularis A vascular strip that lies along the outer wall of the scala media. It is responsible for the secretion and absorption of endolymph, it supplies oxygen and nutrients to the organ of Corti, and it affects the positive DC potential of the endolymph.

Subluxation An incomplete dislocation or sprain.

Sudden idiopathic sensory/neural hearing loss (SISNHL) This condition refers to a hearing loss, usually unilateral, that may develop over the course of a few days or occur seemingly instantaneously with no known etiology.

Superior olivary complex (SOC) One of the auditory relay stations in the midbrain, largely comprising units from the cochlear nuclei.

Superior temporal gyrus The convolution of the temporal lobe believed to be the seat of language comprehension of the auditory system.

Suppurative Producing pus.

Synapse The area of communication between neurons where a nerve impulse passes from an axon of one neuron to the cell body or dendrite of another.

Syndrome A set of symptoms that appear together to indicate a specific pathological condition.

Synthetic sentence identification (SSI) A method for determining word-recognition scores by means of 10 seven-word sentences that are grammatically correct but meaningless.

Tactile response The response obtained during bone-conduction (and occasionally air-conduction) audiometry to signals that have been felt, rather than heard, by the patient.

Tangible reinforcement operant conditioning audiometry (TROCA) A form of operant audiometry using tangible reinforcers, such as food or tokens.

Tectorial membrane A gossamer membrane above the organ of Corti in the scala media in which the tips of the cilia of the hair cells are embedded.

Telecoil (T-Coil) Also known as an audiocoil, an induction coil is frequently built into hearing aids that pick up electromagnetic signals from a telephone or loop induction system.

Temporal lobe The part of the cerebral hemispheres usually associated with perception of sound. The auditory language areas are located in the temporal lobes.

Temporary threshold shift (TTS) Temporary sensory/neural hearing loss, usually associated with exposure to intense noise.

Temporomandibular joint (TMJ) syndrome Pain often felt in the ear, but referred from a neuralgia of the temporomandibular joint.

Tensor tympani muscle A small muscle, innervated by the trigeminal nerve and inserted into the malleus in the middle ear; one of two small muscles in the middle ear that contract in response to intense acoustic stimulation.

Tetrachoric table A table containing four cells designed to test the efficiency and accuracy of hearing-screening measures.

Thalamus Located in the brain base, the thalamus sends projecting fibers to, and receives fibers from, all parts of the cortex.

Threshold In audiometry, the level at which a stimulus, such as a pure tone, is barely perceptible. Usual clinical criteria demand that the level be just high enough for the subject to be aware of the sound at least 50% of the times it is presented.

Threshold of discomfort (TD) See *Uncomfortable loudness level*.

Time-compressed speech A system of recording speech so that it is accelerated, and therefore distorted, but the words remain discriminable.

Tinnitus Ear or head noises, usually described as ringing, roaring, or hissing.

Tolerance level See *Uncomfortable loudness level*.

Tone decay The loss of audibility of a sound produced when the ear is constantly stimulated by a pure tone.

Tonotopic Arranged anatomically according to best frequency of stimulation.

Toynbee maneuver A method for forcing the eustachian tube open by swallowing with the nostrils and jaw closed.

Tragus Small cartilaginous flap forming the anterior portion of the pinna.

Transduce To convert one form of power to another (e.g., pressure waves to electricity, as in a microphone).

Transient-evoked otoacoustic emission (TEOAE) An otoacoustic emission evoked in the cochlea by very brief acoustic stimuli like clicks or tone pips.

Transistor An electronic device, with low power consumption and small space requirements, that amplifies electric current through the use of the semiconducting properties of an element such as silicon.

Transverse wave A wave in which the motion of the molecules of the medium is perpendicular to the direction of the wave.

Trapezius muscle A large, superficial muscle at the back of the neck and upper part of the thorax, or chest. It originates in the occipital bone at the base of the skull.

Trapezoid body Nerve fibers in the pons that connect the ventral cochlear nucleus on one side of the brain with the lateral lemniscus on the other side.

Traveling wave theory The theory that sound waves move in the cochlea from its base to its apex along the basilar membrane. The crest of the wave resonates at a particular point on the basilar membrane, resulting in the perception of a specific pitch.

Trigeminal nerve The Vth cranial nerve, which innervates the tensor tympani and also some of the palatal muscles.

Trisomy The presence of an additional (third) chromosome.

Tuning fork A metal instrument with a stem and two tines. When struck, it vibrates, producing an audible, near-perfect tone.

Tympanic membrane The thin vibrating membrane between the outer and middle ears, located at the end of the external auditory canal. It comprises an outer layer of skin, a middle layer of connective tissue, and an inner layer of mucous membrane.

Tympanogram A graphic representation of a pressure-compliance function.

Tympanometry Measurement of the pressure-compliance function of the tympanic membrane.

Tympanoplasty A surgical procedure designed to restore the hearing function to a middle ear that has been partially destroyed (as by otitis media).

Tympanosclerosis Formation of whitish plaques in the tympanic membrane and masses of hard connective tissue around the bones of the middle ear. This occurs secondary to otitis media and may result in fixation of the ossicular chain.

Umbo A slight indentation at the approximate center of the tympanic membrane at the tip of the malleus; the point at which the tympanic membrane is most retracted.

Uncomfortable loudness level (UCL) That intensity at which speech becomes uncomfortably loud.

Undermasking Occurs when a masking noise presented to the nontest ear is of insufficient intensity to prevent the test signal from being heard in that ear.

Utricle The larger of the two sacs found in the membranous vestibular labyrinth; it contains an end organ of equilibrium.

Vacuum tube A glass enclosure designed to regulate the flow of electric current.

Valsalva Autoinflation of the middle ear by closing off the mouth and nose and forcing air up the eustachian tube.

Variable expressivity The extent to which an inheritable trait is manifested.

Variable pure-tone average (VPTA) The average pure-tone threshold of the poorest three frequencies of 500, 1000, 2000, and 4000 Hz, used for the assignment of hearing-loss-impairment labels. Allows for a representation of hearing loss of either flat configuration or isolated primarily within either the lower or higher frequency range.

Varying Intensity Story Test (VIST) Portions of a story are presented above the admitted "threshold" and portions below. If the patient remembers information presented below the admitted

threshold, this is *prima facie* evidence that the hearing loss in that ear is exaggerated.

Vasospasm The violent constriction of a blood vessel, usually an artery.

Velocity The speed of a sound wave in a given direction.

Ventral cochlear nucleus The larger of the two cochlear nuclei on each side of the brain; it receives the fibers of the cochlea on the ipsilateral side.

Vertigo The sensation that a person (or his or her surroundings) is whirling or spinning.

Vestibular-evoked myogenic potential (VEMP) A sound-evoked muscle reflex believed to be generated from acoustical stimulation of the saccule. It is used in the diagnosis of vestibular disorders.

Vestibule The cavity of the inner ear containing the organs of equilibrium and giving access to the cochlea.

Vibration The to-and-fro movements of a mass. In a free vibration the mass is displaced from its position of rest and allowed to oscillate without outside influence. In a forced vibration the mass is moved back and forth by applying an external force.

Vibrotactile aid A device that delivers amplified vibratory energy to the surface of the skin by special transducers; designed for patients whose hearing losses are so severe that assistance in speechreading cannot be obtained from traditional hearing aids.

Visual reinforcement audiometry (VRA) The use of a light or picture to reinforce a child's response to a sound.

Volley theory of hearing A variation of the frequency theory in which some neurons fire during the refractory periods of other neurons.

Warble tone A pure tone that is frequency modulated. The modulation is usually expressed as a percentage (e.g., a 1000 Hz tone warbled at 5% would vary from 950 to 1050 Hz).

Watt A unit of power.

Wave A series of moving impulses set up by a vibration.

Wavelength The distance between the exact same point (in degrees) on two successive cycles of a tone.

Weber test A tuning-fork test performed in cases of hearing loss in one ear to determine if the impairment in the poorer ear is conductive or sensory/neural.

White noise A broadband noise with approximately equal energy per cycle.

Word Intelligibility by Picture Identification (WIPI) test A test that uses pictures to determine word-recognition ability in young children.

Word-recognition score (WRS) The percentage of correctly identified items on a word-recognition test.

Work Energy expended by displacement of a mass. The unit of measurement is the erg or joule.

X-linked Characteristics transmitted by genes on the X chromosome (sex-linked).



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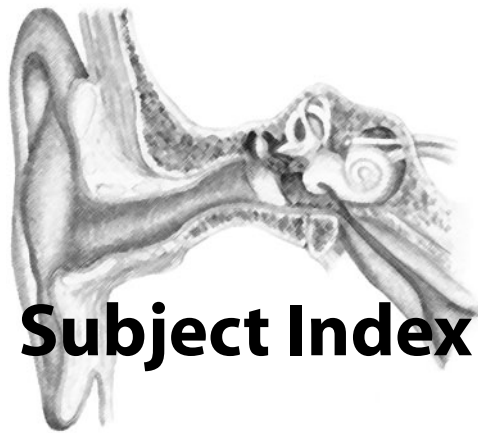
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