

AUDIOLOGY

Science to Practice

THIRD EDITION

STEVEN KRAMER
DAVID K. BROWN

With Contributions By
JAMES JERGER AND H. GUSTAV MUELLER

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AUDIOLOGY
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Third Edition

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Preface

This textbook provides an introductory, yet comprehensive look at the field of audiology. It is designed for undergraduate students, beginning audiology doctoral students, graduate speech-language pathology students, and other professionals who work closely with audiologists. It is expected that the knowledge obtained in this textbook will be applicable to the readers' future education or clinical practices. For some, it may help them decide to go into the profession of audiology.

From science to practice, this textbook covers anatomy and physiology, acoustic properties and perception of sounds, audiometry and speech measures, masking, audiogram interpretations, outer and middle ear assessments, otoacoustic emission and auditory brainstem responses, hearing screening, hearing aids, and cochlear and other implantable devices. Where appropriate, variations in procedures for pediatrics are presented. Beginning students also have a lot of interest in knowing about some common hearing disorders, and this book provides concise descriptions of selected auditory pathologies from different parts of the auditory system, with typical audiologic findings for many of the more commonly found ear diseases and hearing disorders to help the student learn how to integrate information from multiple tests. Also included is a separate chapter on the vestibular (balance) system, for those who wish to learn more about this important aspect of audiology. In addition, there are two chapters describing the profession of audiology, including its career outlook, what it takes to become an audiologist, as well as what audiologists do and where they practice. As a special addition, James Jerger, a legend in audiology, and University of Arizona share their perspectives on the history of audiology in the

United States; these can be found throughout the various chapters as set-aside boxes (Historical Vignettes).

Although this textbook is intended for readers with little or no background in audiology, it is not a cursory overview. Instead, it presents a comprehensive and challenging coverage of hearing science and clinical audiology, but written in a style that tries to make new and/or difficult concepts relatively easy to understand. The approach to this book is to keep it readable and to punctuate the text with useful figures and tables. Each chapter has a list of key objectives, and throughout the chapter key words or phrases are italicized and included in a Glossary at the end of the textbook. In addition, most of the chapters have strategically-placed reviews (synopses) that can serve as quick refreshers before moving on, or which can provide a "quick read" of the entire text. Having taught beginning students for a number of years, the authors have learned a lot about how students learn and what keeps them motivated. After getting the students interested in the profession of audiology, information about acoustics is presented so that they have the tools to understand how the ear works and how hearing loss is assessed (which is what they really want to know) and these areas form the bulk of the text. Of course, the order of the chapters can be changed to suit any instructor.

FEATURES AND ADDITIONS TO THIS EDITION

This third edition of *Audiology: Science to Practice* has been extensively revised from the previous edition. This edition represents a collaboration with a new co-author, David Brown, whose

long-time teaching experience and expertise in audiology and hearing science provided an opportunity to again update and expand the textbook in order to be useful to a wider audience. We also incorporated some of the feedback received through a survey of faculty who were current or interested users of the textbook.

This edition has four new chapters: (1) Outer and Middle Ear Assessment, that now includes a new section on otoscopy, more information on the use of different immittance probe-tone frequencies, and a well-developed section on the use of wideband acoustic immittance (reflectance); (2) Evoked Responses, with more information and examples on the use of OAEs, ABRs, and ASSRs for assessing neural pathologies and auditory sensitivity; (3) Implantable Devices, that covers cochlear implants, bone-anchored hearing aids, and other implantable devices; and (4) Vestibular System for those choosing to include a more comprehensive coverage of vestibular anatomy, physiology, disorders, and assessment. Another substantive change includes a revision of the chapter on Hearing Aids to make it more appropriate for the undergraduate student or others who want an overview of this important part of audiology. The chapter on Disorders of the Auditory System now has figures that include clinical data from a variety of audiology tests, including immittance, speech, and special tests, so that the student can begin to learn to integrate basic audiologic test results for the different disorders.

This edition has systematically reviewed each of the chapters from the previous edition to expand, update, and reorganize the material to make it even more useful to the student new to audiology, and at the same time continuing to be more comprehensive than one might find in other introductory texts on audiology. References and figures have been updated, including photos of new hearing instruments and amplification devices, and some new figures on the anatomy of the auditory and vestibular systems. This edition retains the features that worked well in previous editions, including an easy-to-read format, key learning objectives, and synopses within each chapter with bulleted highlights for review. The chapters are now organized in a more traditional sequence beginning with information about the profession of audiology, followed by acoustics, anatomy/physiology, and clinical audiology. Stylistically, this edition now has some set-aside boxes with ancillary information that are interspersed throughout the textbook, including much of Dr. Jerger's historical account of audiology in the United States. We are excited about all the improvements in this edition that will help beginning students gain an even stronger foundation about audiology concepts.

This edition also comes with a PluralPlus companion website which includes lecture outlines in slide format that can be used in teaching audiological concepts, the full text of Dr. Jerger's essay on the history of audiology, and more.

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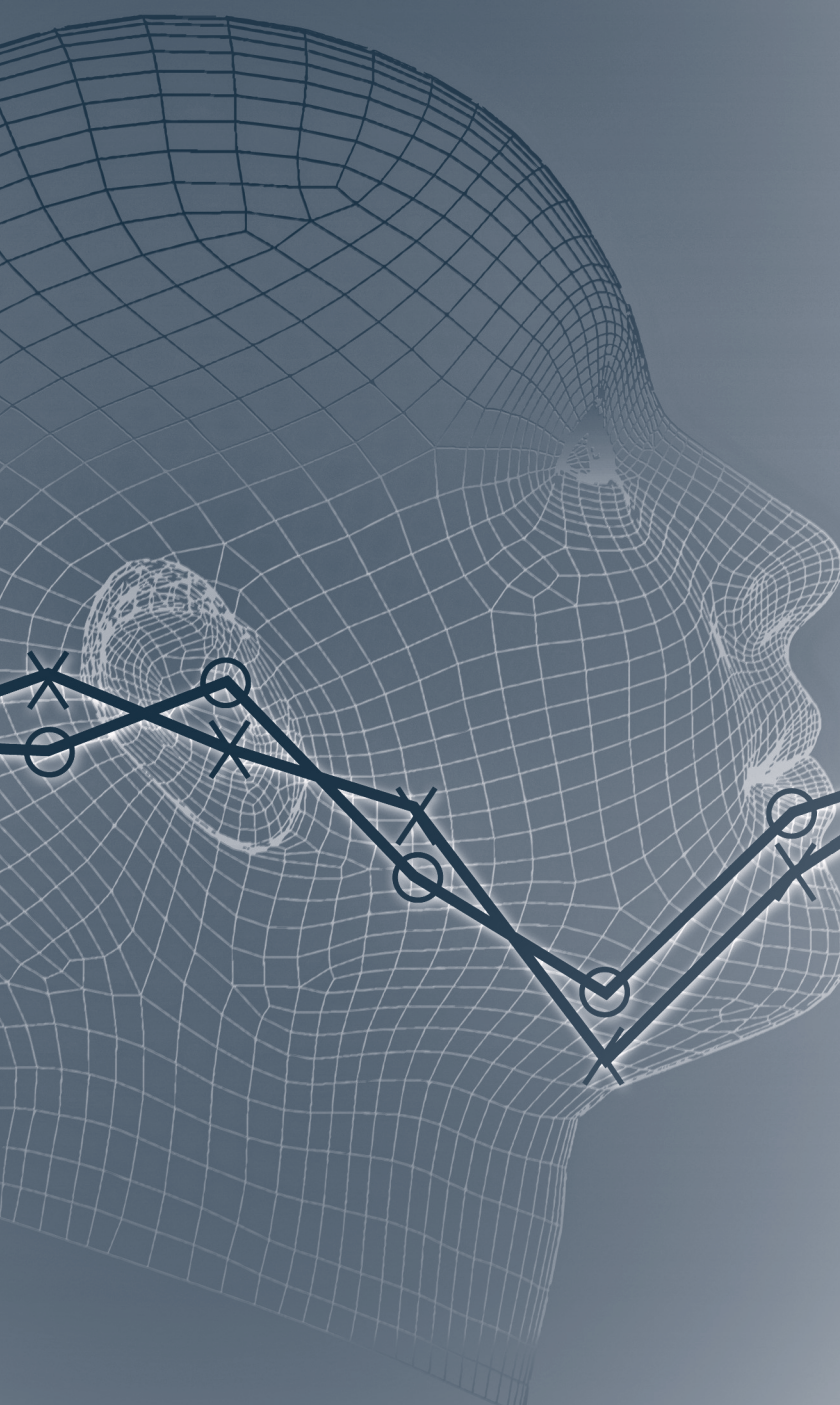
*To the children with hearing impairments on my school bus many years ago,
who inspired me to pursue a career in audiology;
To my past, present, and future students, who have always made my work
enjoyable, challenging, and rewarding;
To my wife, Paula, for her support and sacrifices during the writing of this text;
To my colleagues who provide me with an exciting place to work, and for their
camaraderie and continued support during the revision of this textbook.*

—Steven Kramer

*To my mentors and teachers who spent time answering my questions,
may I spend as much time with my students as you did with me;
To my colleagues, who shared their knowledge with me;
To my students throughout the years who challenged me to learn more;
To my family and especially my wife, Dianne, who gave up and put up with so much
during the writing of this book. I promise I will be home for dinner soon!*

—David Brown

Perspectives on the Profession of Audiology



WELCOME to the fascinating world of audiology! In the first part of this textbook, we will provide you with some information about the profession of audiology. We hope this part provides you with an appreciation for the rewarding aspects of being involved with the profession of audiology. In Chapter 1, you will learn about audiology and its professional organizations. Chapter 1 also includes an overview of the development of the profession, with contributions by Dr. James Jerger, a pioneer and continuing contributor to audiological research. You will also find some of Dr. Jerger's historical perspectives interspersed throughout the textbook as set-aside boxes (Historical Vignettes). An extended version of this historical perspective by Jerger and DeConde Johnson, from the second edition, is available on the companion website. In Chapter 2, you will learn about what is required to become an audiologist, the kinds of settings where audiologists practice, and the kinds of activities that might fill their work week. You will become familiar with the varied paths you might take within audiology and the extensive scope of practice that defines the skills

of audiologists. Chapter 2 also presents some current demographic trends in audiology, as summarized from surveys regularly conducted by our professional organizations. For those interested in speech-language pathology, nursing, optometry, rehabilitation counseling, or other related fields, we know that you will interact with people who have hearing loss and with audiologists, and the information in this textbook will, undoubtedly, be of use to you. We hope many of you will become intrigued by the possibility of joining the profession of audiology.

1

The Discipline of Audiology

After reading this chapter, you should be able to:

- 1.** Define audiology and understand how audiology relates to other disciplines.
- 2.** List some professional and student organizations related to audiology.
- 3.** Become aware of professional websites' resources to learn more about the profession.
- 4.** Discuss how and when audiology as a profession first began, and describe key events that transpired over the years as the profession evolved.

Audiology is a discipline that focuses on the study of normal hearing and hearing disorders. Additionally, audiology includes the assessment and treatment of vestibular (balance) disorders. More precisely, audiology is a health care profession devoted to identification, assessment, treatment/rehabilitation, and prevention of hearing and balance disorders, and understanding the effects of hearing loss on related communication disorders. An *audiologist* is a professional who has the appropriate degree and license in his or her state to practice audiology, and who is, typically, certified by a professional board. Audiologists are the experts who understand the effects of hearing loss on communication and how to best improve a patient's ability to hear.

Audiologists work with many other professionals and support personnel. The medical expert in hearing disorders is the physician. The medical specialty related to the ear is called *otology*, which is practiced by appropriately trained and certified *otologists*, also called neurootologists, otolaryngologists, or ear, nose, and throat (ENT) specialists. Audiologists also work closely with *speech-language pathologists*, who are certified and/or licensed professionals who engage in prevention, assessment, and treatment of speech and language disorders, including those who have hearing loss. In addition, many audiologists are part of interdisciplinary teams, especially when it comes to the assessment and treatment of pediatric patients, as well as patients with implantable devices, cystic fibrosis, cleft palate, or balance problems, to name a few.

PROFESSIONAL ORGANIZATIONS

The *American Academy of Audiology (AAA)* is the professional organization for audiologists. In 1988, AAA (often referred to as “triple A”) was founded in order to establish an organization devoted entirely to the needs of audiologists and the interests of the audiology profession (<http://www.audiology.org>). Originally, AAA focused on transitioning audiology to a doctoral level profession, which became a reality by 2007. Membership in AAA quickly skyrocketed, and, today, AAA has a membership of more than 12,000 audiologists (Amer-

ican Academy of Audiology [AAA], n.d. a). Prior to the formation of AAA, the *American Speech-Language-Hearing Association (ASHA)* was, and still remains, a professional organization for audiologists and speech-language pathologists. The ASHA was established in 1925 as the American Academy of Speech Correction, and went through several name changes including the American Society for the Study of Disorders of Speech (1927), the American Speech Correction Association (1934), the American Speech and Hearing Association (1947), and in 1978 became the American Speech-Language-Hearing Association (American Speech-Language-Hearing Association [ASHA], n.d.). In its early years, ASHA focused on speech disorders; however, during World War II, with service personnel returning with hearing losses, ASHA expanded its mission to include assessment and treatment of those with hearing disorders.

The AAA and ASHA are both strong advocates for the hearing impaired and related services by audiologists, both at the state and national levels. The AAA and ASHA each have professional certifications for audiologists: *American Board of Audiology (ABA) Certification* through AAA, and the *Certificate of Clinical Competence in Audiology (CCC-A)* through ASHA. In addition, each of these organizations can award accreditation to academic programs that meet a set of standards; the Accreditation Commission for Audiology Education (ACAE) associated with AAA, and the Commission on Academic Accreditation (CAA) associated with ASHA.

Audiologists may also choose to join other professional organizations. The Academy of Dispensing Audiologists (ADA) was established in 1977 to support the needs of audiologists who dispense (sell) hearing aids. The ADA later changed its name to the *Academy of Doctors of Audiology (ADA)* (<http://www.audiologist.org>), and expanded its focus to any audiologists in private practice or those who wished to establish a private practice. The *Educational Audiology Association (EAA)* (<http://www.edaud.org>), formed in 1983, is a professional membership organization of audiologists and related professionals who deliver a full spectrum of hearing services to all children, particularly those in educational settings. Many audiologists are also

associated with the American Auditory Society (AAS) (<http://www.amauditorysoc.org>) and/or the Academy of Rehabilitative Audiology (ARA) (<http://www.audrehab.org>). Additionally, there is a national student organization for those interested in audiology, called the *Student Academy of Audiology (SAA)* (<http://saa.audiology.org>). The SAA is devoted to audiology education, student research, professional requirements, and networking of students enrolled in audiology doctoral programs. Undergraduate students who are potentially interested in pursuing a career in audiology may also join SAA (Undergraduate Associate). Most university programs have a local chapter of SAA that is part of the national SAA. Undergraduate programs may also have a chapter of *National Student Speech Language Hearing Association (NSSLHA)*. A wealth of information about the field of audiology and a career as an audiologist can be found on the above-mentioned websites.

DEVELOPMENT OF THE PROFESSION OF AUDIOLOGY¹

Prior to World War II, persons with hearing disorders received services by physicians and hearing aid dispensers (Martin & Clark, 2015). Audiology in the United States established its roots in 1922 with the fabrication of the first commercial audiometer (Western Electric 1-A) by Harvey Fletcher and R. L. Wegel, who were conducting pioneering research in speech communication at Bell Telephone Laboratories (Jerger, 2009). These audiometers were used, primarily, for research and in otolaryngology practices.

Audiology as a profession began around the time of World War II, mostly because of returning service personnel who developed hearing problems from unprotected exposures to high-level noises. Initially, returning armed-service personnel were seen by otologists and speech-language pathologists, but clinical services for those with hearing loss soon evolved into a specialty practice in the United States that became known as

¹Includes contributions by James Jerger and Cheryl DeConde Johnson (adapted with permission).

Historical Vignette

The first genuine audiologist in the United States was, undoubtedly, Cordia C. Bunch. As a graduate student at the University of Iowa, late in World War I, Bunch came under the influence of Carl Seashore, a psychologist who was studying the measurement of musical aptitude, and L. W. Dean, an otolaryngologist. Together, they stimulated Bunch's interest in the measurement of hearing. Over the two decades from 1920 to 1940, Bunch carried out the first systematic studies of the relation between types of hearing loss and audiometric patterns. Bunch's pioneering efforts were published in a slender volume entitled *Clinical Audiometry*, which is now a classic in the field. In 1941, Bunch accepted an offer from the School of Speech at Northwestern University to teach courses in hearing testing and hearing disorders, as part of the education of the deaf program. While at Northwestern University, Bunch mentored a young faculty member in speech science, Raymond Carhart. In 1942, Bunch unexpectedly died at the age of 57. In order to continue the course in hearing testing and disorders, the Northwestern administration asked Raymond Carhart to teach the course. The rest, as they say, is history, as Carhart became another one of the early pioneers of the field.

the field of audiology. While the effects of excessive noise on hearing have been recognized virtually since the beginning of the industrial age, it was not until World War II that the United States military began to address the issues of hearing conservation with a series of regulations defining noise exposure as a hazard, setting forth conditions under which hearing protection must be employed, and requiring that personnel exposed to potentially hazardous noise have their hearing monitored. The introduction of jet aircraft

Historical Vignette

Attempts to exploit the residual hearing of severely and profoundly hearing-impaired persons has a history much longer than audiology. Long before there were audiometers and hearing aids, educators of the deaf were at the front lines of auditory training, using whatever tools were available. Alexander Graham Bell, inventor of the telephone and founder of the AG Bell Association, took a special interest in the possibilities of auditory training because of his wife's hearing loss. He was a strong proponent of the aural approach and lent his considerable reputation to its promulgation in the last quarter of the nineteenth century. Another early supporter of systematic training in listening was Max Goldstein, who founded the world-famous Central Institute for the Deaf in St. Louis.

into the Air Force and the Navy in the late 1940s, generating high levels of noise, was an important factor driving interest in hearing protection. Early studies of the effects of noise on the auditory system were carried out in the 1940s and 1950s at the Naval School of Aviation Medicine, in Pensacola, Florida. Similar research programs were established at the Navy submarine base in Groton, Connecticut, and at the Navy Electronics Laboratory in San Diego, California. After World War II, audiology-specific educational programs were developed in universities to prepare professionals for clinical work, as well as becoming the stage for further research efforts that would define the practice of audiology. In the early years, audiology focused on rehabilitation, including lipreading (now called speechreading), auditory training, and hearing aids.

During the late 1960s and early 1970s, there was a focus on the development of several objective measures of the auditory system: Immittance (known then as impedance) blossomed into tests called tympanometry, used for assessing middle

ear disorders, and acoustic reflex thresholds, used for differentiating/documenting conductive, sensory, and neural losses. The immittance test battery is now standard in basic hearing assessments. The mid to late 1970s brought our attention to the clinical use of evoked electrical potentials, especially the auditory brainstem response (ABR), which provided an objective evaluation of the auditory system that was unaffected by sedation. The ABR continues to be used as a specialty test for neurologic function, and even more importantly for both newborn hearing screening and follow-up hearing threshold assessment. In the late 1970s, otoacoustic emission (OAE) testing was developed as another objective measure of the auditory system, and became an accepted part of clinical practice by the late 1980s. The clinical applicability of OAE testing was the primary impetus for states in the United States to adopt universal newborn hearing screening programs. Marion Downs of the University of Colorado, undoubtedly, had the greatest impact on the testing of pediatrics and, ultimately, the concept and realization of universal hearing screening of all newborns. Dr. Downs founded the first screening program in 1962 and never ceased to push for newborn hearing screening. According to the National Center for Hearing Assessment and Management (NCHAM) at Utah State University, all states and territories of America now have an Early Hearing Detection and Intervention (EHDI) program (National Center for Hearing Assessment and Management, n.d.).

The development of better-designed hearing aids and procedures for hearing aid fittings was also an important step forward in treating those with hearing loss. During the early 1950s, the transistor was developed and its value in the design of wearable hearing aids was immediately apparent. An even greater impact on hearing aid design and miniaturization was the advent of digital signal processing, and by the 1990s, digital hearing aids were becoming the standard. Other important advances in hearing aids included microphone technology and better/smaller batteries. It is interesting to point out that prior to 1977, ASHA considered it unethical for audiologists to dispense hearing aids, except in the Veteran's Hospitals. However, through the continuing in-

terests and activities of audiologists directed toward dispensing of hearing aids throughout the 1970s, ASHA changed its perspective in 1979, and hearing aid dispensing soon became a large part of audiology practices. At the time of this writing (August 2017), the U.S. Congress passed legislation allowing hearing aids to be sold over-the-counter (OTC) for adults with mild to moderate degrees of hearing loss, and established about a three-year time window to develop regulations and implementation.

Cochlear implants (CI) were another milestone in audiology, beginning with the first implants in the 1960s. Subsequently, there was a 30-year, slow-but-steady, convincing of the profession that cochlear implants were able to produce remarkable results in adults and children, and now cochlear implants are well accepted in the audiology community. The progress of cochlear implants over the past three decades has been truly remarkable. The early CI systems were essentially aids to speechreading and few users could maintain a conversation without the aid of visual cues. However, as the number of electrodes increased and speech-coding strategies became more sophisticated, performance in the auditory-only condition improved several-fold. It is now quite reasonable to expect that a person with a cochlear implant will be able to converse, even on the telephone. Thirty years ago, few people would have predicted that this level of performance would ever be attainable.

There has also been a relatively long history in the area of vestibular disorders and testing. Bradford (1975) describes some of the early history in this area that includes the early descriptions of nystagmus (reflexive eye movements) by Purkinje (1820), discovery of the cerebellar and labyrinthine sources of vertigo by Flourens (1828), and the development of caloric testing by Barany (1915). Pioneering work in establishing the clinical use of electronystagmography (ENG) was done by Alfred Coats (e.g., Coats, 1975), Baloh and colleagues (e.g., Baloh, Sills, & Honrubia, 1977), and Barber and colleagues (e.g., Barber and Stockwell, 1980). With advances in technology in the past decade, the electrode-based ENG method evolved to an infrared video camera method for recording eye movements (VNG)

during the vestibular exam. Other advancements include the development of rotary chair testing that rotates the whole body with head fixed in place, and posturography with a platform that allows for tilting the body in different directions. One of the more recent clinical developments is the recording of vestibular evoked myogenic potentials involving the ocular muscles (oVEMP) or the cervical muscles (cVEMP) in response to loud sounds, which have been shown to be useful for assessing the saccule and utricle, which are sensory organs of the vestibular system.

Over the last 70+ years, audiology has evolved (often in parallel) along at least the following eight distinct paths:

- Development of auditory diagnostic tests (behavioral and physiologic)
- Hearing aids and rehabilitation/treatment
- Pediatrics
- Auditory processing disorders (APDs)
- Hearing conservation
- Audiology in the educational (school) systems
- Tinnitus evaluation and therapy
- Development of vestibular tests and rehabilitation

The reader is referred to some of the comment boxes throughout this textbook for overviews of these paths. A more complete historical account of audiology in the United States has been published by Jerger (2009). In addition, Jerger and DeConde Johnson have an expanded chapter on the development of these paths in the second edition of this textbook, which is also available in this textbook's companion website. As Jerger and DeConde Johnson (2014) concluded,

. . . it is interesting to observe the degree to which these paths have interacted. We see the fruits of progress in the diagnostic path reflected in the development of APD testing, the impact of advances in electroacoustics and electrophysiology on universal screening procedures, the influence of cochlear implant advances on auditory training, and the influences of all on intervention with amplification, hearing conservation, tinnitus therapy, and audiology in the educational

SYNOPSIS 1-1

- Audiology is a discipline that focuses on the study of normal hearing and hearing disorders, as well as vestibular (balance) assessment and rehabilitation. Audiology in the United States had its beginnings around the time of World War II.
- An audiologist is a licensed professional who practices audiology, and is an expert on the effects of hearing loss on communication and psychosocial factors. Otology is the discipline primarily related to medical assessment and treatment of hearing and balance disorders, and is the specialty practiced by otologists.
- The American Academy of Audiology (AAA) and the American Speech-Language-Hearing Association (ASHA) are the two main professional organizations serving their audiologist members. The AAA was founded in 1988, and is entirely run by and for audiologists.
- The national student organization for future doctoral level audiologists is called the Student Academy of Audiology (SAA). Most doctoral audiology programs have local chapters of SAA. Many undergraduate programs encourage undergraduates to enroll in student chapters.
- Audiology became a doctoral level profession by 2007, and today the AAA has more than 12,000 members.
- Some key historical milestones in audiology include development of immittance measures (early 1970s), auditory brainstem response (ABR) measures (late 1970s), approval for audiologists to dispense hearing aids (1979), otoacoustic emission measures (1980s), digital hearing aids become the dominant type (1990s), and legislation allowing OTC hearing aids (2017).

setting. These are, we believe, hallmarks of a robust and growing profession with a remarkable history. (p. 380)

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2

Audiology as a Career

After reading this chapter, you should be able to:

- 1.** Understand the academic and clinical requirements that are needed to become an audiologist: Know the basic difference between an AuD and PhD.
- 2.** Know the legal requirements to practice audiology: List two professional certifications that are available to audiologists.
- 3.** Describe various paths/specialties that audiologists might follow to define their careers.
- 4.** Describe the general activities of audiologists and how they might spend their time in any given week.
- 5.** Describe the types of settings in which audiologists typically work.
- 6.** List four to six activities that are within an audiologist's scope of practice.
- 7.** Discuss why some activities within an audiologist's scope of practice might diminish in importance, or disappear in the future.
- 8.** Give an estimate of the number of audiologists there are in its professional organizations and describe the general membership demographics.
- 9.** Access the professional websites of AAA and ASHA to find AuD programs and to learn more about the profession.