

The
AUDITORY
SYSTEM

*Anatomy,
Physiology,
and Clinical
Correlates*

SECOND EDITION



Frank E. Musiek
Jane A. Baran

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Editor-in-Chief for Audiology
Brad A. Stach, PhD



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PREFACE

The first edition of our book, *The Auditory System: Anatomy, Physiology, and Clinical Correlates* was written to provide a comprehensive text on the anatomy and physiology of the peripheral as well as the central auditory systems—an approach that is maintained in the current edition. The approach to this book is slightly different than what is generally planned for books on the structure and function of the auditory system. This book is written primarily for graduate students with a clinical slant in hope of drawing more future and current practitioners into the important process of reading and learning more about the anatomy and physiology of the auditory system. After conducting surveys as well as extensive discussions with students and clinicians, we have learned several concepts and approaches that may make a book on anatomy and physiology more appealing to graduate students and clinicians. These concepts and approaches follow and provide the impetus for this book.

1. As noted by the title of this book, we will highlight clinical correlates to the basic science principles that are being presented. Whenever possible, a case study, a brief review, or a clinical comment will be connected to the basic science principle being discussed. This added clinical information will be highlighted in the text as *clinical or pathologic correlates*. The purpose of this feature is to help establish the link between science and practice in a brief but relevant way. We believe this will make this text more interesting and useful for the clinically oriented student and professional.
2. This book makes generous use of secondary references because many review chapters and articles are often easier to follow and are more relevant to the graduate student and the clinician. Our interaction with clinicians has taught us that basic science articles are not usually read—even when recommended. Instead, review articles are sought for a better grasp on the subject. Hence, we have tried to provide some key basic science readings (original or key articles) for each of the topics covered, and whenever possible, we have also included review articles or chapters as supplementary references. Finally, we have tried to select basic science articles that have a clinical slant or clinical implications for inclusion in this text.
3. In the past decade or two, considerable interest and research has been focused on neuroscience and the central auditory system. However, prior to this time, far more attention was devoted to the peripheral system. In this text, we have tried to balance the coverage of the peripheral and central systems so that the reader can be exposed to both portions of the auditory system in sufficient depth to be able to appreciate the nature of the processing that occurs at the two levels. The text will present information regarding the similarities in the auditory processes conducted at the two levels, as well as the unique types of processing that occur not only between the two levels, but also among some of the structures within each level of the auditory system.
4. Although it has been difficult to do, we have tried to use the human model as much as possible in our discussion of the anatomy and physiology of the auditory system. So much work has been completed

on animals and so little on humans that it often was a challenge to limit the discussion to the human model—but a serious effort has been made to do this in this book.

5. This book is aimed at the graduate student—especially those enrolled in doctor of audiology (Au.D.) programs who need to understand the anatomy and physiology of the human hearing mechanism as it is relevant to clinical audiology. A number of Au.D. programs have split their hearing science course into two courses: one on anatomy and physiology and one on psychoacoustics. We feel this is an appropriate approach and one for which this book is well suited. This book was also written to provide the practicing clinician with a relevant reference source that can be easy to use.
6. The fields of anatomy and physiology have exploded, with large quantities of new research information appearing in the literature on a regular basis. Most of this is important indeed, but it is not always relevant to the clinician. We therefore have tried to sort out what is most salient to the audiologist (perhaps our most difficult task) and keep the book at a reasonable length.

IMPORTANCE TO THE CLINICIAN

An understanding of the biological aspects of the auditory system is essential to the knowledgeable clinician. At first glance many clinicians perhaps wonder how knowledge of anatomy and physiology of the auditory system will help them in their everyday activities. However, if one closely reflects upon what a clinician in hearing and hearing disorders does on any given day, the role of biology becomes obvious. A number of clinical activities come to mind that are dependent on the provider being familiar with the structure and function of the auditory system.

Communication with other clinicians in the same as well as different disciplines can be enhanced greatly by understanding anatomy and physiology. Long-lasting opinions are formed in the clinical arena by brief discussions of difficult patients, diagnoses, and treatments. One who is well grounded in anatomy and physiology can better understand and contribute to these types of discussions.

Clinicians are responsible, to varying degrees, for test selection and interpretation. These are the evaluation tools that are critical to the proper diagnosis of the patient. Tests are a measure of function and function is intimately related to structure. Knowing how to administer a test but not understanding the underlying functions that it is assessing is doing only half of the job. For example, an absent acoustic reflex is of little value if one does not know the anatomy of the acoustic reflex circuit. Clinicians well oriented toward the anatomy and physiology of the hearing mechanism are in a much better position to optimally utilize tests and interpret test results than those who are not.

Radiological information is becoming more available and more sophisticated. Diagnostic clinicians can be helped by radiological information on a patient. However, radiology is a specialty that is based on anatomy. Without anatomical knowledge, radiological information cannot be utilized efficiently. Correlating test results with radiological findings is the backbone of diagnostic audiology, and the establishments of such correlations (or lack of) cannot be accomplished without a solid anatomical grounding.

Clinicians work with people who have a variety of auditory disorders. In order to understand a given disorder, the locus and function of the structure(s)

affected must be known. At times the anatomy and physiology related to a given disorder may provide insight as to the nature of the problem and what is to be expected. For example, we know that kernicterus primarily compromises the cochlear nucleus in the brainstem even though it often manifests as a high-frequency sensorineural hearing loss, which could be interpreted as a peripheral problem. Utilizing only a peripheral audiological evaluation would miss the key aspects of this disorder.

Finally, patient counseling is dependent on knowledge of the anatomy and physiology of the auditory system. Better explanations of the patient's problems come from clinicians who understand the basics of structure and function. Anatomical models and illustrations can help enhance understanding for the patient. With common use of the Internet, patients are more knowledgeable and can ask demanding questions about the underlying anatomy and physiology of their disorders. Many of them know and appreciate what has been known in science for many years: that anatomy along with its physiology is the common denominator for understanding how we hear or do not hear. It therefore is critical for hearing health care professionals to have a solid grounding in anatomy and physiology in order to be able to effectively counsel patients with auditory disorders and to be able to answer their patients' questions with knowledge and confidence.

NEW FEATURES

In our second edition of this book the reader will notice a number changes and updates. Though not all of these can be covered in detail here, there are several changes that are worth mentioning. One of the major additions is Chapter 16, which presents an overview of normal development of the auditory system, plasticity of the central auditory system, and aging effects on the peripheral and central auditory systems. This new chapter reviews basic studies that focus on auditory system changes over the lifespan that have a clinical impact. Chapter 3 includes several new illustrations of the anatomy and physiology of the middle ear. Among the new illustrations is a set of photos showing a variety of pathological conditions of the tympanic membrane. In Chapter 4 on cochlear anatomy the reader will notice several new illustrations and a discussion of synaptic ribbons highlighting novel findings in regard to deleterious interactions between the inner hair cells and the auditory nerve when exposed to noise without the usual accompanying hearing loss. In Chapter 6 some new views on the role of neuropharmacology of cochlear function are discussed. Chapter 12 includes both text and illustrative changes which focus on a discussion of cryoloop cooling as a new procedural approach to better elucidate the effects of pathology on the auditory cortex. In addition, new information on tonotopic organization of the auditory cortex and the variable locus of the angular gyrus is offered in this chapter. Finally, in Chapter 14 updated information on the vascular network of the brainstem, specifically the vertebrobasilar system, is provided.

CLOSING COMMENTS

We trust that this book has helped make explicit the link between the structures and functions of the auditory system and the specific clinical correlates that are tied to the underlying basic science principles and concepts that have been presented. It was with much deliberation and careful consideration of this

intent that we decided on the title for our text: *The Auditory System: Anatomy, Physiology, and Clinical Correlates (2nd Edition)*. Finally, we hope the reader of this book will become a better, more informed provider of care to individuals with hearing loss and hearing deficits, having gained these insights.



ACKNOWLEDGMENTS

The second edition of *The Auditory System: Anatomy, Physiology, and Clinical Correlates* presents a new set of challenges for which I received much help from many people. I am grateful to many people who have helped me in a variety of ways with this book. For many years Jane Baran, my coauthor, has been a close friend and colleague. Her many contributions to the completion of this work have been immeasurable, and I thank her for these and her continued support. A special thanks to The Royal Arch Research Assistance (RARA) people who have helped support much of the work that contributed to this book. I also want to thank Tony Sahley for his insightful review and revisions of Chapter 6. I would also like to acknowledge the help from my students in the NeuroAudiology Lab, Speech, Language and Hearing Department at the University of Arizona—at the risk of omission they include: Nicole Denny, Barrett St. George, Alyssa Everett, Laura Sommerfield, Bryan Wong, and Aaron Whitely. Appreciation is also extended to Plural Publishing—especially Angie, Val, and Nicole for all their help and encouragement.

Finally I wish to thank my gracious and lovely wife, Sheila, and my two wonderful sons, Erik and Justin, for their constant support and interest in everything I do.

—FM

I also am grateful to the many fine individuals who have contributed in many important ways to this book. First and foremost I want to thank my colleague and coauthor, Frank Musiek. I have had the privilege and honor of working with him for many years, and this book is but one of the fruits of this collaboration. Without his diligence, persistence, and insights, this book would not have become a reality. He is one of those rare individuals who is not only a good colleague but also a valued and trusted friend.

I also would like to recognize the individuals that Frank Musiek has identified in his acknowledgments. I will not mention all of these individuals again here, but I would like to add my sincere thanks to all of these individuals, as each of them has made an important contribution to the completion of this edition of our book, *The Auditory System: Anatomy, Physiology, and Clinical Correlates*.

Finally, I especially want to thank my husband, David Hoffman, and my daughter, Sarah Jane, who continually offered their encouragement, assistance, and support throughout this endeavor.

—JAB



ABOUT THE AUTHORS

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Jane A. Baran, PhD, CCC-A/SLP, is Professor Emerita in the Department of Communication Disorders at the University of Massachusetts Amherst. Her primary research and clinical interests are in the areas of (central) auditory processing disorders, auditory evoked potentials, and neuroanatomy and neurophysiology of the auditory system. She is coauthor of three books, *Neuroaudiology: Case Studies*, *The Auditory System: Anatomy, Physiology and Clinical Correlates*, and *Disorders of the Auditory System*. In addition, she has authored or co-authored a number of journal articles and book chapters in the areas of normal and disordered auditory processing, language processing, auditory evoked potentials, and auditory neuroanatomy and neurophysiology. She has presented numerous research papers and educational workshops at regional, national, and international meetings. Dr. Baran is a Fellow of the American Speech-Language-Hearing Association (ASHA), the 2001 Recipient of the Clinical Educators Award from the American Academy of Audiology, a 2005 Recipient of a Recognition Award for Special Contributions to Higher Education from ASHA, and the 2013 Recipient of the Journal of the American Academy of Audiology Editor’s Award. She also is one of a select group of scholars to receive the Carnegie National Scholar Fellowship Award from the Carnegie Foundation for the Advancement of Teaching and Learning.



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1

Overview of the Anatomy and Physiology of the Auditory System



INTRODUCTION TO THE AUDITORY SYSTEM

One of the key features of this book is a balanced review of the two major portions of the auditory system; i.e., the peripheral and central auditory systems (Figure 1-1). The peripheral system includes the outer ear, the middle ear, the cochlea, and the auditory nerve (AN). The central auditory system includes the cochlear nucleus (CN), the superior olivary complex (SOC), the lateral lemniscus (LL) (both nuclei

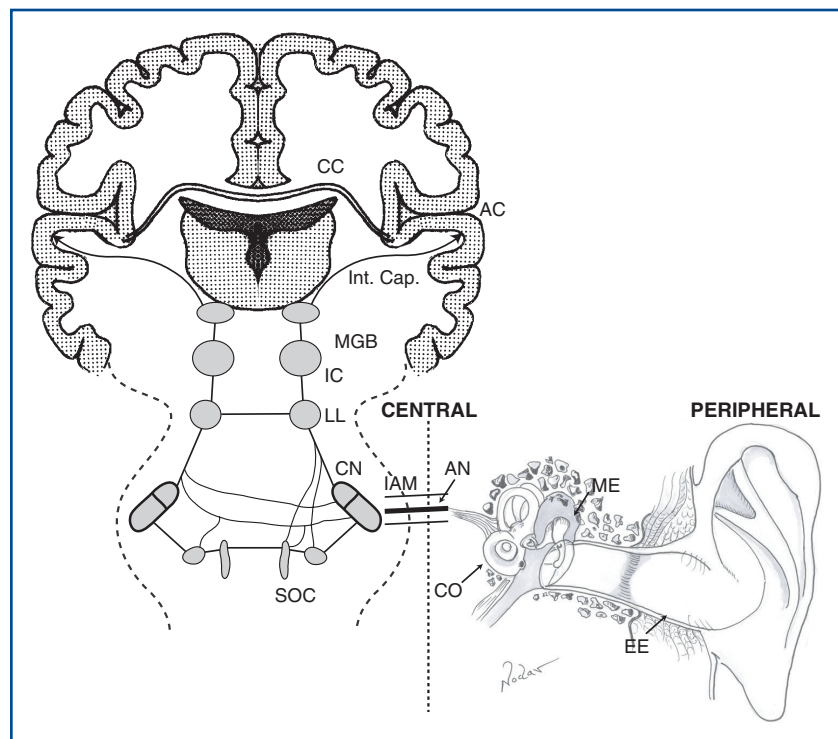


Figure 1-1. Highly schematized drawing of the peripheral and central auditory systems. KEY: EE = external ear and canal, ME = middle ear, CO = cochlea, AN = auditory nerve, IAM = internal auditory meatus, CN = cochlear nucleus, SOC = superior olivary complex, LL = lateral lemniscus, IC = inferior colliculus, MGB = medial geniculate body, Int. cap. = internal capsule, AC = auditory cortex, CC = corpus callosum.

and pathways), the inferior colliculus (IC), the medial geniculate body (MGB), the auditory subcortex (subcortical white matter and basal ganglia region), the cortex, and the interhemispheric pathways (including the corpus callosum).

The peripheral auditory system is located for the most part in the temporal bone, which is part of the cranium, and the central auditory system is located in the brain. Specifically, the CN, SOC, and LL are situated in the pons, the IC is in the midbrain, and the MGB is in the caudal thalamus. The auditory subcortex and cortex involve structures such as the internal capsule, the insula, Heschl's gyrus, the planum temporale, and other parts of the superior temporal gyrus. Auditory responsive areas also include segments of the frontal lobe, the parietal lobe, the angular gyrus, the supramarginal gyrus, and the corpus callosum. This entire system is often referred to as the auditory afferent system, meaning it courses from the ear up to and including the brain. There is also an efferent system, which is almost the reverse of the afferent system in that it runs a similar, but not an identical, route but from the cortex down to the cochlea.

In general, the auditory system performs two kinds of processing of acoustic stimuli—sequential and parallel. Sequential processing involves the transferring of information from one area or level of the auditory system to the next. This type of processing lends itself to a hierarchical organization as one ascends the auditory afferent system. Parallel processing, on the other hand, involves overlapping functions that occur at about the same time along different channels. Both of these major types of processing are needed for optimal



CLINICAL CORRELATE

In diagnostic audiology, considerable effort is expended in differentiating conductive hearing loss from sensorineural hearing loss. Conductive hearing loss involves dysfunction or compromise of the conductive apparatus (i.e., the outer and/or middle ear). Most conductive hearing losses can be medically or surgically corrected, whereas the majority of sensorineural losses are not typically amenable to medical intervention, which means that they tend to be permanent. The hearing deficits associated with conductive and sensorineural losses are quite different in their nature; therefore, it is important for the clinician to differentiate these two types of losses so that the best management approaches can be implemented.

Although much of the early diagnostic work in audiology was directed toward differentiating conductive versus sensorineural hearing losses, the focus was centered primarily on differentially diagnosing conductive versus "sensory" hearing losses (i.e., hearing losses originating within the inner ear or cochlea). More recently, however, because of advances in both basic science and diagnostic methods, it has become important for the audiologist to identify cochlear versus retrocochlear (all structures beyond the cochlea) dysfunction. This need to differentially diagnose cochlear versus retrocochlear lesions was initially driven by the fact that many lesions within the auditory system

involved lesions of the AN or serious lesions of the brain. Hence, the accurate identification of the site of lesion had important implications for the medical management for many patients with retrocochlear lesions. Even more recently, it has become important for audiologic management purposes that cochlear sites of lesion be differentiated from retrocochlear sites even if the lesions are benign. This is because a different set of hearing problems arise from compromise of the retrocochlear system compared with those seen with involvement of the cochlea. Most recently, audiologists have begun to diagnose and manage central auditory disorders or central auditory processing disorders (CAPDs). These disorders are caused by dysfunction or compromise of the auditory system in the brain. Central auditory disorders are retrocochlear disorders that exclude disorders arising from the AN.

It therefore has become increasingly important for audiologists to know and to be able to define the different areas of the auditory system as various regions are responsible for various auditory functions. Each area within the auditory system contributes its own special aspect of acoustic signal processing. However, it is also important to realize that the auditory system is well orchestrated and works as a whole. The different parts of the auditory system are in fact interdependent.