

Auditory Processing Disorders

ASSESSMENT, MANAGEMENT, AND TREATMENT

THIRD EDITION

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

Auditory Processing Disorders

ASSESSMENT, MANAGEMENT,
AND TREATMENT

Third Edition

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Foreword

The concept of auditory processing disorder has had a long and complicated history. Although it has recently been strongly associated with children, its roots go back to research on adults with brain tumors. In the 1950s, a group of Italian otolaryngologists, Ettore Bocca and his colleagues, were interested in the effect of temporal lobe tumors on speech perception. In those days it was accepted wisdom that hemispheric lesions had little or no effect on speech understanding; indeed, it was often said that you could do without an entire hemisphere without affecting speech understanding. Neurologists, of course, were well aware of the effects of even small brain lesions on language processing, especially Wernicke's aphasia, but short of that the link to simple speech recognition tests was not commonly made. But Bocca and his team thought the matter had not been adequately studied. They set out to research the issue until they had a definitive answer. They began by testing these brain tumor patients with the Italian word lists used for standard audiometry, but could find no real deficits. They had the feeling, however, that the tests were too easy. They reasoned that if the tests could be made more difficult, something would turn up. One of the things they tried, in order to in their words "sensitize" the tests, was time compression. Lacking present-day digital recording techniques, they had the talker who was recording the materials simply talk faster. They tried lists of single words, whole sentences, voice

distortion, systematic interruption, low pass filtering, and simply presenting the test items at a level only 5 dB above threshold (faint speech). They described all of this collectively as "low redundancy" speech. From all of this research they learned two things very clearly. First, when you made the test items more difficult by any of these "sensitization" schemes, there was a clear loss in speech understanding, and performance was poorer on the ear contralateral to the hemisphere affected by the tumor, striking testimony to the prepotency of the crossed over pathways between the ears and the cerebral hemispheres. Moreover, ear differences were often striking. Second, simply low-pass filtering the speech worked as well as any of the other, more complicated, techniques.

These Italian studies were read with great interest by many American audiologists, who saw it as a solution to the problem of how to test for auditory processing problems in children. The notion of a "central" auditory processing problem had been in the wind since Helmer Myklebust introduced the term in his 1954 book, *Auditory Disorders in Children*. A number of American audiologists were well aware of the fact that teachers and mothers often complained that there were children who simply did not "hear well," even though formal audiometric testing seldom revealed any deficit. Perhaps, audiologists thought, the answer lay in making the audiometric tests more difficult, "sensitizing" them. If persons with known

brain lesions perform poorly on some kind of auditory test, and someone else performs poorly on that same test, but who does not have a hearing loss, a child then could be diagnosed with a "central auditory processing problem."

A number of audiologists applied the sensitization idea to tests designed specifically for such children. One of the earliest tests for children, SCAN-C, for example, relied heavily on a low-pass filtered component. An individual child's performance on the test could be described as abnormal if it fell outside the 95% confidence interval generated by a suitable normative group. Since these pioneering works, testing for auditory processing disorder has become something of a cottage industry.

Fortunately, while some disagreements remain, this book reminds us that we have long ago moved beyond such simplistic views of an auditory processing disorder. We have made significant progress over the past 50 years in understanding the complex interactions among speech, language, child development, and cognitive development. We have a better understanding of the need for more comprehensive testing over many dimensions. And we appreciate the importance of a team effort including many other disciplines besides audiology. We have a broader grasp of how to understand, address, and remediate the problems presented by children who need special help. And such a broad comprehensive view warrants an equally comprehensive textbook.

The editors of this volume have assembled an impressive team of individual contributors, each a respected authority in a specific area. Together they cover virtually every dimension of auditory processing disorder (APD), from modern diagnosis, through access technologies, to remote microphone technology, to educational and clinical management of APD. Each chapter has been assigned to an experienced and authoritative author or team of authors. Coverage is broad, thorough, and complete. This will be an excellent textbook for a course in APD as well as a resource for clinicians and researchers.

Naturally everyone approaches a book differently depending on their particular interest. I was especially impressed by Chapter 2 in which Donna Geffner clearly lays out the field of battle, Chapter 4, in which Sharon Cameron and Harvey Dillon present an extraordinarily innovative approach to diagnosis, Chapter 7 where Deborah Swain outlines the speech-language pathologist's important role in the equation, and Chapter 8, Gail Richard's contrast of auditory and language problems. Also, do not miss Chapter 11. Doris Bamiou's chapter on neurological brain damage, and Chapter 5, by Nina Kraus and Spencer Smith, "Thinking Outside the Sound Booth."

Well, these chapters happened to square most with my own interests, but there is something in this book for anyone touched in any way by the unique problems these children and adults present.

James Jerger, PhD
August 2017

Preface

The first edition of *Auditory Processing Disorders: Assessment, Management, and Treatment* was first published in 2007 with the second edition following in 2013. The concept of auditory processing disorder (APD) was introduced to our professions in 1954 by Helmer Mylebust. Since that time technology and instrumentation have enabled the professions to make tremendous advances in the neurophysiology, neuroanatomy, definition, assessment, management, and treatment of APD. However, since its inception and the years in between, this topic of research and study has been thwarted with controversy despite the magnitude of advances.

This third edition represents the tireless ongoing study, research, and clinical application by the best minds in the field of APD throughout the world. Their contributions document not only the existence of APD but the advances in assessment, management, and treatment in children and adults who are faced with the challenges imposed by the disorder. Ultimately, because of the contributions of such experts as Nina Kraus, Charles Berlin, Jack Katz, Teri James Bellis, Gail Chermak, Harvey Dillon, Sharron Cameron, Frank Musiek, Jeanne Ferre, Gary Rance, Jeff Weihing, Gail Richards, Margaret Burns, Vivian Iliadou, Doris Bamiou, Jay Lucker, Carol Lai, Janet McCarty, Bunnie Schuler, Dan Peters, and many more associate authors—a Who's Who among authors, clinicians are better able to make enlightened decisions and recommendations for assessment,

management, and treatment, resulting in better outcomes for the clients.

Though perspectives and opinions relative to APD continue to be controversial among the professional community, the advances, as presented in this third edition, speak for themselves. This third edition offers a more comprehensive and thorough reflection of the study of APD with some new authors, research, and clinical findings, as well as new discoveries, further documentation to an already established and definitive discipline. One merely has to look at the voluminous body of work dedicated to the science to realize its existence.

This third edition, like the previous two, is divided into three sections: Identification, Management, and Evidence-Based Treatment and Intervention Programs. Written by audiologists, speech-language pathologists, and third-party subject matter experts, the content of this book is intended to provide a variety of professionals with useful and practical information that will improve their understanding of APD relative to assessment, interpretation, management, and intervention. With a heightened knowledge base, we are all better able to serve the children, their parents, and adults with this disorder and foster collaboration with other professionals who interact with this population, promoting interprofessional collaboration.

The authors are indebted to the contributing authors who worked tirelessly and expediently to produce this third edition of *Auditory Processing*

Disorders: Assessment, Management, and Treatment. Their knowledge, expertise, and clinical practice have been compiled from around the world to advance this field of study, as well as provide the most current and relevant information for clinical application. We thank our contributors for their com-

mitment and dedication to this field of study. A special thank you to Lindsay Lerro for her superb assistance. Their contributions are invaluable in advancing the knowledge base, and more importantly, in improving clinical outcomes for those individuals whose lives are impacted by APD.

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5

Thinking Outside the Sound Booth: Assessing and Managing Auditory Processing Disorder in an Auditory-Cognitive Neuroscience Framework

Nina Kraus and Spencer B. Smith

Overview

Auditory processing disorder (APD) has traditionally been viewed within a *site-of-lesion* framework in which deficits are hypothesized to arise from impaired function of one or more specialized subunits of the auditory nervous system. This view is useful when examining patients with frank neurologic insults; however, in most cases of APD, no specific lesion can be found. In this chapter, we propose an *auditory-cognitive neuroscience framework* of auditory processing in which the “canonical” auditory pathway interfaces with cognitive, sensorimotor, and reward brain centers. Importantly, plasticity within this system can have *adaptive* or *maladaptive* consequences: auditory enrichment (e.g., musicianship or bilingualism) augments auditory-cognitive function while auditory deprivation (e.g., auditory-based learning disorders, poverty, or head injury) weakens it. Using a biomarker of auditory-cognitive function,

the frequency following response (FFR), we explore how both auditory expertise and disorder influence brain function. We conclude by offering suggestions for conducting auditory processing evaluations with the auditory-cognitive neuroscience framework in mind and review literature on remediation of auditory-based deficits using auditory training and FM systems.

Introduction

Professional and public awareness of auditory processing disorder (APD) has increased dramatically over the past two decades due to the collective efforts of expert task forces convened by the American Speech-Language-Hearing Association (ASHA) (2005 a, 2005b), American Academy of Audiology (AAA) (2010), and British Society of Audiology (BSA) (2011). Greater awareness, however, has not translated into greater clarity or clinician confidence regarding the etiology, diagnosis, and management of APD, and the disorder remains controversial. A survey of the APD literature suggests that this controversy arises in part from inadequate theoretical frameworks through which APD can be understood and empirically investigated (Cacace & McFarland, 2009, 2013; DeBonis & Moncrieff, 2008; Moore, 2006). For example, many clinical tools used to assess APD were developed by testing patients with frank neurological lesions, such as individuals with war-related head injuries, temporal lobe seizures/defects, and corpus callosectomies (Chermak & Musiek, 2013; Jerger, 2009). This *site-of-lesion* framework has been valuable in pinpointing areas of the brain involved in constituent aspects of auditory pro-

cessing. However, in most cases of APD, a punctate site-of-lesion cannot be identified and the etiology may arise from a more diffuse combination of auditory and cognitive dysfunction (Bishop, Carlyon, Deeks, & Bishop, 1999; Hendler, Squires, & Emmerich, 1990; Jerger, Johnson & Loiselle, 1988; Moore, Ferguson, Edmondson-Jones, Ratib, & Riley, 2010; Moore, Rosen, Bamiou, Campbell, & Sirimanna 2013; Rappaport et al., 1994; Watson & Kidd, 2002).

Audition and cognition are tightly and reciprocally coupled; therefore, our view is that auditory-cognitive neuroscience can teach us a great deal about the nature of APD and how to remediate it (Banai & Kraus, 2007; Kraus & White-Schwoch, 2015; Moore et al., 2013; Musiek & Chermak, 2013; White-Schwoch & Kraus, 2017). We view the auditory-cognitive system as a distributed but integrated circuit in which the “canonical” auditory pathway provides a flexible scaffold that is shaped by cognitive interaction with sound over the lifespan. Importantly, the propensity of the auditory-cognitive system to *learn* can have *adaptive* or *maladaptive* consequences: auditory enrichment augments its function while auditory deprivation weakens it (Figure 5–1). Cases of both auditory expertise (e.g., musicianship) and disorder (e.g., auditory-based learning

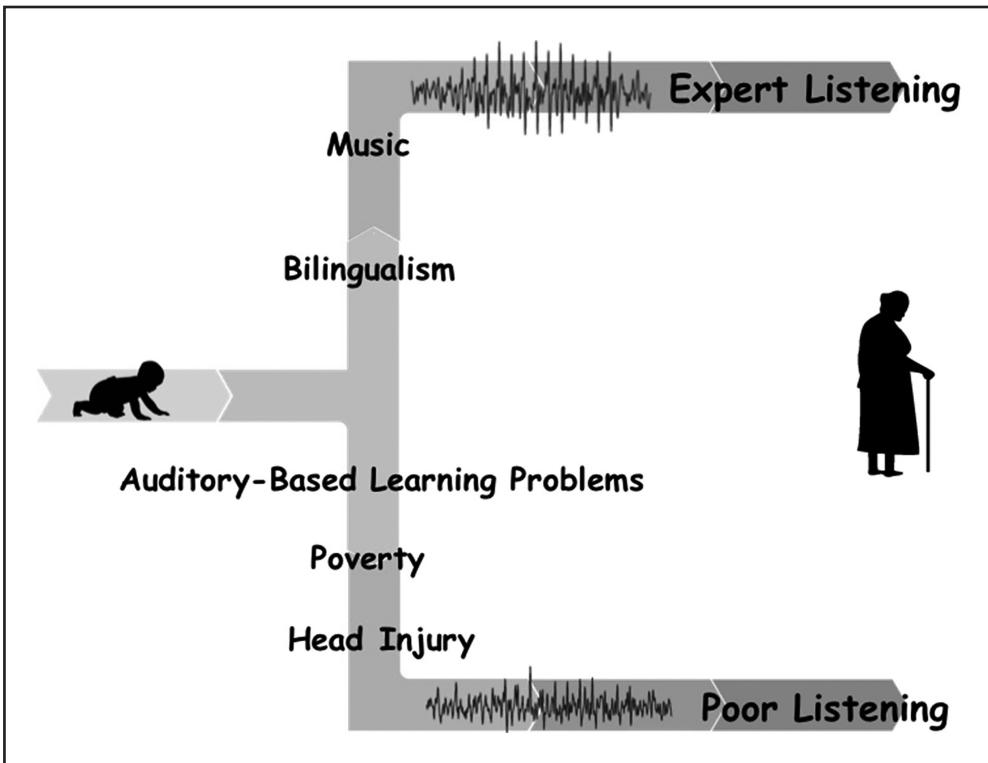


Figure 5-1. The auditory-cognitive system is shaped by adaptive or maladaptive learning over the lifespan. Adaptive learning supports expert listening, whereas maladaptive learning may underlie various disorders resulting in poor listening.

problems) provide insights into how different experiences mold auditory-cognitive system function and allow us to understand the nature of disorders as well as how training can positively impact the brain (White-Schwoch & Kraus, 2017). While an auditory-cognitive framework of APD may seem more abstract than a site-of-lesion framework to clinicians “in the trenches,” it places diagnostic and remediation emphasis on deficits of *function* rather than *feature*. Therefore, the auditory-cognitive framework is very much in the spirit of recommendations from the abovementioned taskforces on APD in guiding “the development of

more customized, *deficit-focused* intervention plans” (ASHA, 2005a).

We begin this chapter by exploring the neural substrates of the auditory-cognitive system and discuss how neuroplasticity inherent to this system facilitates auditory learning. We then review how adaptive and maladaptive auditory learning across the lifespan have been evaluated in our lab using a combination of objective (i.e., electrophysiological) and subjective (i.e., behavioral) assessments. The chapter concludes with a proposed outline for APD evaluation that is guided by assessing the auditory-cognitive system holistically

and some discussion of evidence-based interventions.

Learning and Plasticity in the Auditory- Cognitive System

Classic models of auditory processing posited that information proceeded sequentially through specialized stations of the auditory system with computational analysis becoming more complex at each ascending level (e.g., Webster, 1992). This view has been eroded to the point of near collapse by the preponderance of evidence demonstrating that the auditory system is bidirectional, highly interactive, and diffusely influenced by experience (Atiani, Elhilali, David, Fritz, & Shamma, 2009; Bajo, Nodal, Moore, & King, 2010; Bajo & King, 2012; Dragicevic et al., 2015; Fritz, Elhilali, David, & Shamma, 2007; Gao & Suga, 2000; Kraus & White-Schwoch, 2014; Leon Elgueda, Silva, Hamamé, & Delano, 2012; Mulders & Robertson, 2000; Ota, Oliver, & Dolan, 2004; Polley, Steinberg, & Merzenich, 2006; Rajan, 1990; Zhang & Dolan, 2006; Xiao & Suga, 2002).

Extensive afferent and efferent auditory pathways provide the neural scaffold for auditory learning to occur within a circuit from cochlea to cortex and back (see Celesia & Hickok, 2015 for an anatomical review). Perhaps some of the most compelling data on efferent modulatory effects on the afferent auditory system come from experiments in which auditory cortex or brainstem neurons were deactivated (either pharmacologically or temporarily via cryoloop cooling) or electrically stimulated in animal models. For example, cochlear outer hair cell and auditory nerve fiber func-

tion were modulated with activation or deactivation of the efferent system “upstream” in both the auditory brainstem and cortex (Dragicevic et al., 2015; Leon et al., 2012; Mulders & Robertson, 2000; Rajan, 1990; Ota et al., 2004; Zhang & Dolan, 2006). Further, the characteristic frequency of stimulated neurons in the auditory cortex (Xiao & Suga, 2002) and brainstem (Mulders & Robertson, 2000) corresponded with the frequency of maximum outer hair cell and auditory nerve fiber modulation. Such effects are demonstrative of the degree to which top-down influences can extend to the most peripheral sites in the auditory system to shape how sound is processed.

Importantly, afferent and efferent auditory pathways not only interact with each other but with cognitive, sensorimotor, and reward centers in the brain (Figure 5–2; Kraus & White-Schwoch, 2015); this combination is a potent force both for online modulation of auditory function and neural remodeling (Atiani et al., 2009; Bakin & Weinberger, 1996; Bidelman, Schug, Jennings, & Bhagat, 2014; Bidelman & Howell, 2016; Bidelman, Schneider, Heitzmann, & Bhagat, 2017; Chandrasekaran, Hornickel, Skoe, Nicol, & Kraus, 2014; Kilgard & Merzenich, 1998; Kraus & White-Schwoch, 2015; Perrot & Collet, 2014; Smith & Cone, 2015; Zatorre, Chen, & Penhune, 2007; Wittekindt, Kaiser, & Abel, 2014). While classic studies of auditory learning demonstrated that cortical sound representation could be altered by behavioral conditioning (Galambos, Sheatz, & Vernier, 1955), research from the intermediate years has demonstrated that, as long as the efferent auditory system is intact, learning can occur even in the auditory subcortex (e.g., Bajo et al., 2010; Gao & Suga, 2000). Further, performance improvements associated with auditory

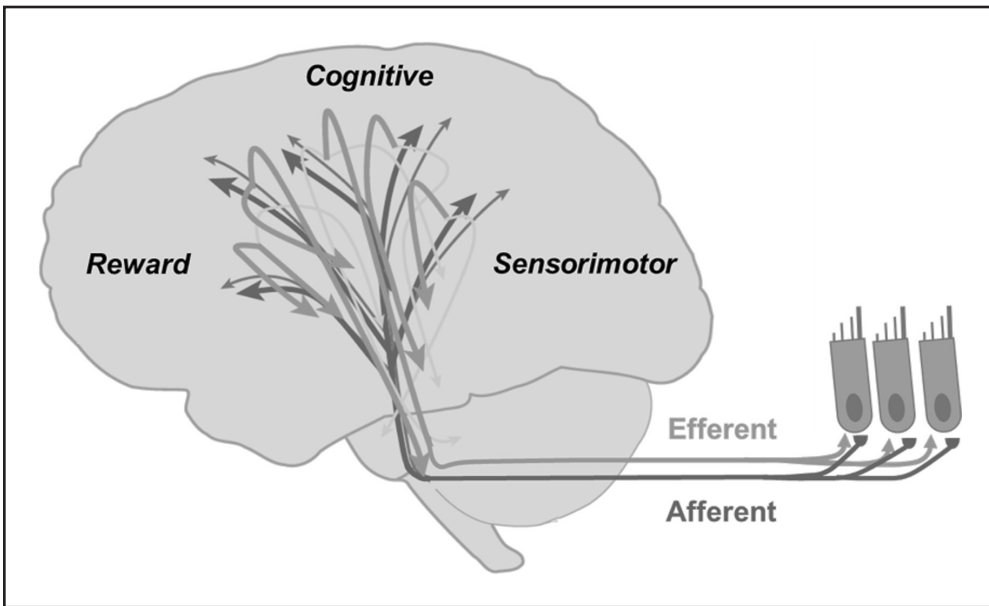


Figure 5-2. Afferent (gray) and efferent (blue) auditory systems provide the neural scaffolding for auditory-cognitive learning to occur. These pathways connect with cognitive, sensorimotor, and reward networks, which drive the process of learning. Adapted from Kraus & White-Schwoch, 2015.

learning persist long after the cortical shifts facilitating these changes have disappeared (Reed et al., 2011), suggesting that although the cortex is important for *initiating* auditory learning by linking sound to meaning, the subcortex may act as a primary repository in which those meaningful relationships are stored and automatically activated (Atiani et al., 2009; Fritz et al., 2005; Kilgard, 2012).

Assessing Learning and Plasticity in the Human Auditory System

The primary approach that we have used to understand the human auditory-

cognitive system and the effects of adaptive and maladaptive auditory learning is a neurobiological measure of brain function known as the frequency following response (FFR).¹ The FFR (Figure 5-3) is a sound-evoked electrical potential recorded from the scalp that is mainly generated by the inferior colliculus (Chandrasekaran & Kraus, 2012; Krishnan, 2002; Smith, Marsh, & Brown, 1975; Smith, Marsh, Greenberg, & Brown, 1978; Sohmer, Pratt, & Kinarti, 1977; but also see Coffey, Herholz, Chepesiuk, Baillet, & Zatorre, 2016). Unlike other auditory evoked potentials, the FFR physically resembles the evoking stimulus; it therefore captures the brain's representation of a multitude of speech (e.g.,

¹The FFR has also been referred to by our lab and others as the "auditory brainstem response to complex sound" or cABR.

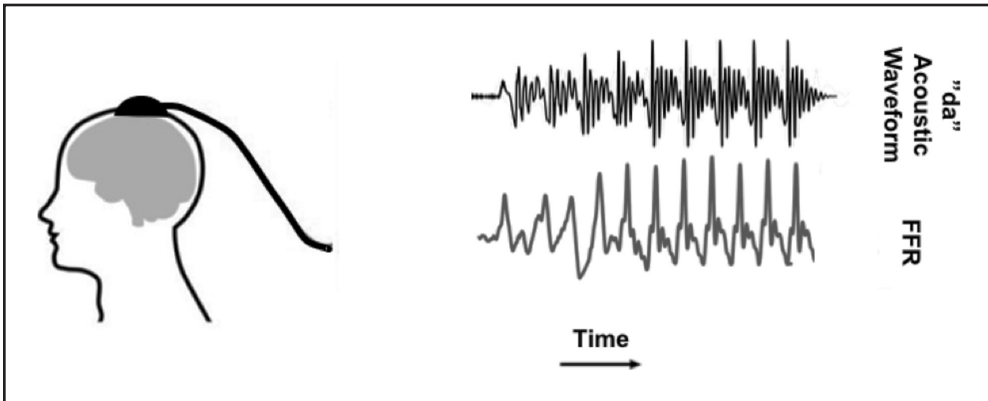


Figure 5-3. The FFR is a scalp recorded neural potential in which the brain's response (bottom waveform) mimics the input stimulus (top waveform) with precision. The FFR can be analyzed in myriad ways to extract how well the brain represents various aspects of sound.

voice pitch, harmonics, vowel formants, and consonant identities), music (e.g., pitch, timbre, attack, and consonance/dissonance), and other complex stimulus features. Further, FFRs can be assessed with regard to their stability and similarity to the input stimulus to discern the integrity, reproducibility, and quality of neural processing (see Skoe & Kraus, 2010 for an in-depth tutorial). Because the FFR is tightly coupled to a major convergence hub of multisensory afferent and efferent information in the inferior colliculus (Winer, 2006), it provides an extremely sensitive measure to study auditory learning due to both lifelong and short-term training experiences (Chandrasekaran, Skoe, & Kraus, 2014).

Adaptive Learning through Auditory Enrichment

Auditory enrichment contributes to greater neurobiological and cognitive

function (Arnon et al., 2006; Engineer et al., 2004; Huttenlocher, 2009; Norena & Eggermont, 2005; Webb, Heller, Benson, & Lahav, 2015; White-Schwoch & Kraus, 2017). In our work, we have investigated the neural effects of auditory enrichment in musicians and bilinguals using the FFR (e.g., Krizman et al., Marian, Shook, Skoe, & Kraus, 2012; Skoe, Marian, & Kraus, 2014; Musacchia, Sams, Skoe, & Kraus, 2007; Strait, Parbery-Clark, Hittner, & Kraus, 2012; Wong, Skoe, Russo, Dees, & Kraus, 2007). In both instances, the auditory-cognitive system is more efficient at automatically processing specific aspects of sound through experience-related tuning of attention; the specific features that are accentuated through these types of enrichment, however, differ.

Musicianship

The effects of musical training on the brain are profound. In comparison to nonmusicians, lifelong musicians show