



CHAPTER 8

THE NATURE OF CENTRAL AUDITORY PROCESSING DISORDER

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Historically, there has been much debate among professionals in many disciplines regarding the nature of central auditory processing disorder (CAPD) and the best means of diagnosing and treating it. In recent years, professionals in the fields of audiology, speech-language pathology, education, and related disciplines have witnessed a dramatic upsurge in interest regarding CAPD in both children and adults, and the demand for central auditory services has surged. As a result, it has become even more crucial that clinicians understand the fundamental principles underlying central auditory processing and its disorders.

The previous chapters in this volume have discussed the scientific bases of

central auditory processing, both neurobiological and psychoacoustic, that inform our current conceptualization of CAPD, as well as etiologic factors that may underlie the disorder. Because an understanding of the fundamental nature of any disorder is critical to appropriate diagnosis and intervention, this chapter discusses key factors affecting central auditory processing and the current definition of CAPD, including how the disorder may lead to or be associated with difficulties in learning, language, communication, and related function. The topic of subprofiles of CAPD in children and adults also are explored, as are areas for future research in central auditory diagnosis and treatment.

Factors Affecting Central Auditory Processing

The way in which a disorder is defined directly informs how it should be diagnosed and treated, and by whom. In the case of CAPD, it is important to note that information to guide our conceptualizations of the disorder derives not only from the auditory neuroscience literature, but also from research in cognitive neuroscience, neuropsychology, psycholinguistics, and a host of other fields. As with any information processing in the brain, central auditory processing is complex and interactive, and an understanding of the fundamental nature of such processing is critical to the development of ecologically valid definitions for the disorder.

Bottom-Up and Top-Down Factors in Central Auditory Processing

Several factors must be taken into account when defining CAPD. First, one must recognize that although CAPD is generally considered to be a “bottom-up” deficit in fundamental auditory mechanisms, the relative influence of “top-down” factors in processing of auditory input cannot be overlooked. That is, although most current definitions of CAPD emphasize dysfunction in the central auditory nervous system (CANS), one must also consider the overarching effects of higher level, attention, cognitive, language, and related systems on fundamental sensory processing. In addition, although the auditory areas of the brainstem and cerebrum are of particular interest when considering CAPD, it is critical to recognize that

parallel, distributed networks throughout the brain involving both inter- and intrahemispheric connections are activated during even the most basic sensory task. Furthermore, activity in lower level (e.g., brainstem) central auditory structures has been shown to modulate—and be modulated by—higher level cortical structures (e.g., Banai, Nicol, Stecker, & Kraus, 2005). As such, while CAPD is conceptualized as an auditory disorder, the complex and interactive nature of information (including auditory) processing leads to a great deal of heterogeneity in how the disorder presents in children and adults and also contributes to the frequently observed comorbidity of CAPD with other disorders involving attention, learning, and related functions. See Chapter 6 for additional discussion of bottom-up and top-down interactions.

Resource Allocation

A second, related factor is critical to our understanding of how disorders in central auditory processing can manifest: resource allocation. Resource allocation theory states that, during information processing, a finite store of resources is available to allocate to tasks. As such, any circumstance that requires disproportionate energy or effort to be allocated to one portion of a task leaves fewer resources for the remaining tasks. For example, the presence of a challenge to fundamental sensory input, such as peripheral hearing loss or a noisy listening environment, may create a situation in which the listener must allocate additional resources toward hearing, leading to fewer resources available for higher-order functions. As such, decreased memory for and/or comprehension of

auditory stimuli may occur when sensory input is disrupted even in the absence of primary memory, language, or related disorder (e.g., Peelle, Troiani, Wingfield, & Grossman, 2010; Pichora-Fuller, Schneider, & Daneman, 1995; Stewart & Wingfield, 2009; Wingfield, McCoy, Peelle, Tun, & Cox, 2006). Conversely, individuals with higher order attention, cognitive, or related deficits may exhibit decreased performance in tests of fundamental sensory processing due to the extra allocation of effort necessary to attend to, comprehend, or remember the stimulus (e.g., Bellis, Billiet, & Ross, 2011). That these effects occur at a neurobiological level is evidenced by the findings of Peelle, Troiani, Grossman, and Wingfield (2011), who demonstrated that even relatively mild deficits in peripheral auditory function lead to alterations in neural activity in brainstem, thalamus, and cortex. Changes in loci of neural activity also occur in normally hearing individuals when the auditory signal is degraded (Davis & Johnsrude, 2003; Harris, Dubno, Keren, Ahlstrom, & Eckert, 2009; Obleser, Wise, Dresner, & Scott, 2007) or when the auditory input is complex (e.g., Obleser, Meyer, & Friederici, 2011). Moreover, these effects can occur across modalities, so that increased effort to attend to a visual distractor may affect neurophysiologic representation of auditory stimuli, resulting from an inability to divide limited attentional resources (Wilson, Harkrider, & King, 2012). As such, one could reasonably expect that “auditory memory” or “auditory comprehension” may be compromised in an individual for whom bottom-up sensory processing, either in the peripheral or central auditory system, is deficient, due to disproportionate allocation of effort toward processing of the basic sensory stimulus.

Nonmodularity of the CANS

A third, also related, factor that must be considered when developing a definition of central auditory processing and its disorders is the degree to which CANS disorders can be expected to manifest solely in the auditory system. The topic of modality specificity as a diagnostic criterion for defining and diagnosing CAPD has enjoyed substantial attention in the literature in recent years and has given rise to two primary dissenting viewpoints. In the first, the clinical utility of a diagnosis of CAPD hinges on the ability to demonstrate that the deficit is restricted to the auditory modality (Cacace & McFarland, 2005; McFarland & Cacace, 1998). In this viewpoint, sensory processing is considered to be modality specific; therefore, analogous tests in other sensory modes (e.g., visual) should be incorporated into the diagnostic test battery in order to confirm that the deficits observed are not apparent across modalities. When deficits are found across modalities, one must infer that either sensory disorder exists in more than one modality or that the disorder is pansensory or global, rather than representing dysfunction in the CANS. This viewpoint is predicated upon the contention that sensory systems are fundamentally modular, and therefore disorders of such systems should, likewise, be specific to the modality involved.

The dissenting viewpoint contends that while some areas of the CANS do respond primarily (but not solely) to auditory stimuli, the majority of the central nervous system (CNS) is nonmodular and composed of convergent sensory tracts, multisensory neurons, and inter- and intrahemispheric connections that preclude conceptualization of any central processing disorder as entirely modality

specific (Musiek, Bellis, & Chermak, 2005). This viewpoint draws upon a large body of research demonstrating the interconnectedness among and multimodal responses in brain regions previously considered to be sensory specific (e.g., Bamiou, Musiek, & Luxon, 2003; Poremba, Saunders, Crane, Cook, Sokoloff, & Mishkin, 2003; Salvi, Lockwood, Frisina, Coad, Wack, & Frisina, 2002; see Stretfeld, 1980 and Musiek et al., 2005 for reviews). Further, this viewpoint holds that due to the uncertain neurophysiologic mechanisms underlying multimodal tests purported to be *analogous* to validated central auditory measures (Musiek et al., 2005), a more appropriate method of disentangling the relative effects of central auditory dysfunction and higher-order, global, or pansensory deficits is to make use of multidisciplinary assessments, with each area addressed by the tests (and professionals) standardized (and qualified) to do so. Finally, this perspective predicts that comorbid deficits across sensory systems may occur due to shared neuroanatomical substrates, which would be entirely consistent with the complex nature of information processing in the CNS.

Direct support for the latter viewpoint has been provided by Bellis and colleagues (Bellis et al., 2011; Bellis, Billiet, & Ross, 2008; Bellis & Ross, 2011), who demonstrated that tasks reliant on shared brain regions (e.g., corpus callosum) give rise to similar patterns of performance regardless of sensory modality but that those individuals with central auditory disorders exhibit deficits that are more pronounced in the auditory modality. Furthermore, the authors' results were consistent with the expectation, derived from information processing and resource allocation theories dis-

cussed previously, that individuals with higher order, attention-related disorders may exhibit overall performance decrements on sensory tasks, but their *patterns* of performance differ from those with CAPD. Finally, and perhaps more importantly, results of this study demonstrated that the addition of visual analogs of central auditory tests did not provide additional information pertinent to diagnosis of CAPD that was not obtained via inter- and intratest comparisons of individual performance on the auditory tests alone.

These interrelated factors—bottom-up and top-down processing, resource allocation, and nonmodularity of the CANS—help to drive our understanding and, ultimately, our definition of central auditory processing and its disorders. When taken together with the plethora of evidence demonstrating the effects of CANS dysfunction on auditory and related functions, a definition of CAPD that accurately reflects the nature of auditory processing in the CANS can be developed.

Defining CAPD

Early definitions of CAPD were rather amorphous and included processes and behaviors ranging from fundamental auditory skills to higher order functions such as linguistic analysis, memory, and use of auditorily presented information (e.g., ASHA, 1992; Kelly, 1995). Because CAPD can lead to or be associated with a variety of functional deficits in learning, language, and communication, as discussed subsequently in this chapter, professionals from a wide variety of disciplines, including speech-language pathologists, audiologists, psychologists,

and neuropsychologists, educators and educational diagnosticians, physicians, and others, began applying the label of CAPD to their patients, often on the basis of symptoms alone and without benefit of any auditory testing whatsoever. As such, CAPD became a “wastebasket term” used to describe any difficulty with auditory input or spoken language. This was a primary factor that led to the controversy surrounding the clinical utility of a diagnosis of CAPD (e.g., Cacace & McFarland, 1998; McFarland & Cacace, 1995; Rees, 1973) because the disorder, as conceptualized by many, was virtually indistinguishable from a host of other disorders with overlapping symptoms, including language disorder, attention deficit hyperactivity disorder (ADHD), and other higher order cognitive disorders, and many other impairments that may affect an individual’s ability to listen to, comprehend, remember, or act upon auditory information.

In response, subsequent definitions of CAPD were more concise and emphasized the auditory-specific nature of the disorder. Thus, many of these definitions either stated or strongly implied that a diagnosis of CAPD should be made only when it could be demonstrated that the disorder is specific to the auditory modality (e.g., Cacace & McFarland, 2005; Jerger & Musiek, 2000; McFarland & Cacace, 1995). However, these definitions, too, were fraught with difficulty, as they failed to recognize the complex, nonmodular, and interactive nature of brain function, with its proliferation of shared neuroanatomical substrates, multisensory neural interfaces, convergence and divergence of sensory “tracks,” and interdependence of bottom-up and top-down factors, all of which were discussed in the previous section.

An additional definition of CAPD was proposed by the British Society of Audiology (BSA, 2011). In this definition, CAPD is purported to represent a more general cognitive and/or developmental disorder rather than a bottom-up, auditory deficit per se. Much of this definition is derived from the findings of Moore and colleagues (Moore, Ferguson, Edmonson-Jones, Ratib, & Riley, 2010) in a population-based study of typical children, of whom those with lower cognitive performance (e.g., verbal memory) tended also to score lower on tests of auditory perception developed by the research team. In addition, the authors found that attention deficits tended to affect auditory test performance adversely. However, when one considers the influence of top-down factors and resource allocation on sensory processing, as discussed in the previous section, these findings are not surprising. Indeed, they are precisely what would be predicted and are entirely consistent with the contentions of Bellis with respect to the relationship between auditory performance and higher order tasks (e.g., Bellis, 2003; Bellis et al., 2011). In addition, it is important to note that the tests employed by Moore et al. (2010) were presumed by the research team to reflect central auditory processing ability; however, sensitivity and specificity of these tests to CANS dysfunction was never documented. Nonetheless, based upon their definition of CAPD, the BSA (2011) contended that CAPD is best identified via parent/caregiver and/or teacher checklists of key behaviors, rather than sensitized tests of auditory function, despite considerable evidence that such checklists are of very limited utility in differentiating children with CAPD from those with other disorders that have similar and/or overlapping symptoms (Comeaux,