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Auditory Dysfunction Beyond the 8th Nerve: Understanding Central Auditory Processing Disorders

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Abstract

Central auditory processing disorder (CAPD) refers to a deficit in the neural processing of auditory stimuli that can affect listening, language, and learning. Because CAPD manifests behavioral symptoms similar to those exhibited by listeners with peripheral hearing loss, it is important that the audiologist be prepared to "go beyond the 8th nerve" in the assessment process to evaluate central auditory skill sets and provide intervention as needed. Differential diagnosis of these disorders is accomplished using behavioral and electrophysiological tests that examine the array of auditory skills and integrity of the system from brainstem through the cortex. Test results are used to develop effective deficit-specific intervention plans designed to reduce/resolve the deficit and minimize the disorder's affect on the listener's life.

Central auditory processing disorder (CAPD) refers to a deficit in the perceptual (i.e., neural) processing of auditory stimuli and the neurobiological activity underlying that processing (American Speech-Language-Hearing Association [ASHA], 2005). Neuro-geographically, the central auditory system ranges from the cochlear nuclei through the cortex and includes the neural encoding of frequency and temporal cues by specific afferent centers as well as the binaural representation of those cues within the system. Both hearing loss and central auditory processing disorders can adversely affect communication, learning, and psychosocial wellness. Thus, the listening/hearing complaints of the listener with a CAPD are similar to those of individuals with peripheral hearing impairment. In fact, many disorders present behavioral characteristics similar to CAPD that may lead to similar functional listening difficulties. Disorders co-existing with and/or sharing symptoms of CAPD include neurocognitive disorders (e.g., attention deficit hyperactivity disorder—ADHD, executive function disorder), cognitive impairment (e.g., mental retardation), communication disorders (e.g., autistic spectrum disorder, Asperger's syndrome, language processing disorders, specific language impairment), social-emotional disturbance (e.g., behavior disorders), learning disability, and other sensory processing impairments (e.g., sensory integration disorder; ASHA, 2005; Bellis, 2006; Ferguson, Hall, Riley, & Moore, 2011; Keller, Tillery, & McFadden, 2006; Sharma, Purdy, & Kelly, 2009; Witton, 2010). Through differential diagnosis, the assessment team uncovers the nature of the underlying disorder contributing to a listener's functional challenges and maximizes the intervention for those challenges.

Differential diagnosis refers to the differentiation among two or more disorders that have similar symptoms and/or manifestations (ASHA, 2005; Bellis, 2006, 2014). Comprehensive differential evaluation of CAPD requires input from a variety of disciplines, including, but not limited to, audiology, speech-language pathology, neuropsychology, occupational therapy (OT), physical therapy (PT), education, and other related professions. The audiologist administers well-controlled tests, sensitive to dysfunction in the central auditory pathways, thus clarifying the *auditory* component, if present. Other professionals provide information regarding the extent to which there exist difficulties in other sensory processing skills and/or in higher-order cognitive, linguistic, or learning skills that may confound auditory test results or co-exist with a CAPD.

In general, the central auditory skill sets include auditory discrimination, binaural processing and temporal processing, and within these sets, specific skills have been identified. Sound localization and lateralization depend upon discrimination and binaural processing. Specific temporal processing includes temporal discrimination, ordering, integration, and masking. Auditory performance in the presence of competing signals requires dichotic listening, dependent upon binaural integration and separation. Some binaural tasks also tax discrimination (e.g., binaural fusion). Tests of auditory performance with degraded acoustic signals tax both auditory closure and discrimination skills. Finally auditory pattern recognition is associated with temporal and discrimination functions (ASHA, 1996, 2005; Bellis, 2003; Chermak & Musiek, 1997). With a goal of understanding the central auditory "lay of the land," as it were, a comprehensive assessment will include both formal and informal measures designed to assess all of these skills.

There is general agreement among audiologists that a battery of tests is essential for the differential diagnosis of a CAPD. While there is less agreement on exactly which specific tests should be included, there is agreement that a comprehensive diagnostic assessment should include verbal and nonverbal tasks as well as behavioral and electrophysiologic/electroacoustic measures. The central auditory evaluation may include the following elements:

- puretone air and bone conduction audiometry to examine peripheral hearing acuity;
- speech reception threshold and word recognition tests to establish baseline word recognition abilities;
- otoacoustic emissions, tympanometry, acoustic reflex, and reflex decay to rule out middle ear disorder, identify retrocochlear dysfunction, and/or differentiate a CAPD from auditory neuropathy;
- measures of brainstem level binaural interaction that may include binaural fusion, masking level difference, and/or assessment of localization to a sound in space;
- low pass filtered and/or time compressed speech tests to tax auditory discrimination;
- dichotic listening tests having varying linguistic loads to assess cortically-based binaural integration and separation skills;
- pitch and/or duration sequencing tasks, "global" measures providing information regarding the integrity of right-hemisphere-based pattern recognition, frequency or temporal discrimination, and interhemispheric transfer of function;
- electrophysiological assessment of the brainstem and/or cortex, e.g., ABR, cABR, MLR, MMN, P300 (Kraus & Hornickel, 2013; Schochat, Rabelo, Musiek, 2014);
- speech-in-noise tests that provide information regarding the listener's functional abilities in various listening situations.

Central auditory processing tasks are measures that, in general, examine how efficiently the auditory system operates by "overloading" or "overworking" it. Central auditory tests go beyond standard tests of hearing to examine how well the auditory system uses or interprets the information that the ear sends it. Results are compared to an age-matched peer group and performance profiles emerge that provide insights into the nature of the CAPD. As with any other clinical decision-making paradigm, it is the responsibility of the examiner to understand fully the nature and limitations of specific central auditory tests as well as the test-taking needs of the client, including chronological and/or developmental age. There remains on-going debate regarding the youngest age for which central auditory assessment is appropriate. While an in-depth discussion of this debate is beyond the scope of this paper, a brief discussion of central auditory skill development is appropriate.

As noted above, central auditory abilities include binaural interaction, auditory discrimination, auditory pattern recognition, dichotic listening, and interhemispheric integration.

Neurodevelopmentally, these skills are present and measurable by 6 years of age, with some skills apparent at much younger ages than others (Bellis, 2003). Reliable diagnostic testing can be accomplished beginning at age 6 as there are versions of most central auditory tests with vocabulary and normative data available for children 6 years and older. For children between the ages of 4–6 years, an assessment including formal tests and informal screening indices examine the precursors of auditory processing. While not specifically diagnostic in nature, the "preschool" assessment provides information regarding a child's strengths and weaknesses with respect to developing auditory processing skills and can serve as a baseline for later assessments, as needed. To date, there are no *behavioral* central auditory tests appropriate for use with children under age four. By understanding the nature of the skills subserved by the peripheral and central auditory systems, we can assess development of the skills, draw inferences regarding impact of impaired or delayed skill development on the child's life, and develop deficit-specific intervention programs designed to reduce/resolve deficits and minimize adverse effects.

Binaural interaction refers to how well the two ears work together and reflects integrity of the auditory system at the low brainstem level. Binaural interaction assists the listener in localizing a sound in space and is important for attention, and listening in noise. Rudimentary binaural interaction ability is present by age two, as suggested by auditory brainstem testing.

Auditory discrimination is the ability to analyze fine differences in the speech spectra that contributes to recognition of running speech, recognition of speech in noise, phonemic/phonologic awareness, and language development. The ability is present at birth, becoming restricted to native language sounds by approximately 12 months of age, and becoming adult-like by age 10 (Bellis, 2003).

Temporal pattern recognition is the ability to identify and/or recognize auditory patterns (i.e., signals with more than two separate acoustic events). Pattern recognition depends on intact temporal resolution ability—the ability to "hear" where one sound ends and another begins—as well as intact right hemisphere function. Pattern recognition contributes to the listener's ability to recognize and process running speech as well as to perceive *intent* of a message, such as in sarcasm. Temporal resolution improves significantly from ages 3–5 years and is adult-like by age 10; while specific pattern recognition is apparent initially at approximately age 6 years and matures through age 12 (Bellis, 2003).

Interhemispheric integration refers to the communication between the two hemispheres across the corpus callosum that contributes to our ability to process increasingly lengthy or complex speech, recognize competing auditory targets, follow directions, synthesize multiple targets as in phonologic processing, transition from task-to-task, and complete assignments in timely fashion. Integration contributes to overall processing speed/efficiency as well as to the ability to manage the breadth and depth of sensory information that we encounter daily. Corpus callosum (i.e., interhemispheric connections) development begins during the first year of life but is not fully mature until early adulthood and is highly variable in listeners under age six (Bellis, 2003).

Dichotic listening refers to the ability to process different information presented to each ear simultaneously. Dichotic listening assists listeners in processing multiple incoming acoustic targets (binaural integration) and/or to ignore target in presence of competing signal (binaural separation). Dichotic listening is present and measurable by age 5, remaining highly variable until age 8, and reaching adult-like values by age 12 (Bellis, 2003).

Central auditory processing disorders (CAPD) do not exist in a vacuum and many clients come to the evaluation with co-existing concerns including peripheral hearing impairment, especially among our aging clients, receptive and/or expressive speech-language issues (e.g., dyspraxia, poor receptive vocabulary, and aphasia), and/or neurocognitive or behavioral issues (e.g., TBI, cognitive impairment, attention deficit disorder, and emotional dysregulation or disorder). While these co-existing challenges do not necessarily exclude the individual from assessment, consideration must be given to them as these factors may require an adjustment to the diagnostic protocol and/or confound test interpretation. Excellent discussions of considerations for diagnostic testing may be found in Bellis (2003); Geffner & Swain (2013), and Musiek & Chermak (2014).

Understanding central auditory processes (CAP) and ably administering a CAP test battery represents only half of the CAPD equation, the examiner must now turn attention to interpreting the results *and* developing a deficit-specific intervention plan. To that end, there exist CAP test profiling systems that assist the examiner in conceptualizing and clarifying test findings. While multiple models exist representing differing conceptualizations of CAPD, all share the notions that a multidisciplinary approach is needed for the assessment process, a test battery is needed for specific CAPD diagnosis, test scores should relate to functional needs, and intervention should be collaborative in order to be effective (ASHA, 2005; Bellis, 2003, 2014; Chermak, 2007; Ferre, 2006). Diagnostic interpretation using one such model is described here.

Bellis and Ferre (1999) outlined five central auditory processing test profiles that describe the nature of the disorder based on key central auditory test findings and measures of cognition, communication, and/or learning, and associated behavioral manifestations. The model is a theoretical framework in which individual test scores as well as inter- and intra-test patterns of performance are examined in order to relate central auditory test findings to both their presumed underlying neurophysiological bases and functional sequalae (ASHA, 2005; Bellis, 2003, 2006; Bellis & Ferre, 1999; Ferre, 2002, 2006). The model describes three primary central auditory deficit profiles characterized by presumed underlying site of dysfunction. Two secondary profiles yield unique patterns of results on central auditory tests; however, they may be described more appropriately as manifestations of supramodal or cognitive-linguistic disorders. For a comprehensive discussion of these deficit profiles, the reader is referred to Bellis (2003, 2006), and Bellis and Ferre (1999). For the purposes of this discussion, they are described briefly here.

Auditory decoding deficit is a deficit in auditory closure and related sound discrimination representing dysfunction in the primary (usually left) central auditory pathways. On central auditory tests, the profile is characterized by difficulty on tests of degraded speech tests (e.g., recognition of filtered or time-compressed targets) and/or measures of temporal discrimination (e.g., temporal gap detection). Binaural and/or right ear deficits may be observed on dichotic listening tests, especially those with relatively substantial linguistic demand (e.g., dichotic words versus dichotic digits). Poor discrimination means the listener's auditory system is working harder than that of a typical listener to extract the fine acoustic changes within the speech spectrum, even under optimal conditions. This difficulty places the listener at risk for listening difficulties when noise is present, in highly reverberant environments (e.g., arenas, restaurants, playgrounds, etc.) when extra visual and/or contextual cues are not available, or when listening to a soft-spoken speaker or one with a pronounced accent. As the acoustic or linguistic conditions deteriorate, more neural energy is expended to process the acoustic portions of the signal, leaving less energy for higher-order linguistic-cognitive processing. Processing inefficiency can result in fatigue and reduced listening comprehension. These behavioral listening difficulties are similar to those observed among listeners with peripheral hearing loss. Like the listener with peripheral hearing impairment, secondary psychosocial issues may arise including social withdrawal or depressive disorder. Auditory decoding deficit can create secondary difficulties in communication (e.g., vocabulary, syntax, semantics, and second language acquisition) and/or academic skills (e.g., reading decoding, spelling, notetaking, and/or direction following; Bellis & Ferre, 1999).

Integration deficit reflects deficient ability to recognize and use multisensory incoming cues quickly and efficiently, believed to be the result of inefficient communication across the corpus callosum. The profile is characterized on central auditory tests by excessive left ear suppression on dichotic listening tests combined with poor labelling but adequate imitation of tonal patterns (e.g., pitch sequencing test). Deficit in skills needed for information integration may affect listening comprehension, especially in groups, academics, and higher-level language processing.

Deficits in other integrative skills (e.g., visual-motor, auditory-visual, etc.) are common with this profile (Bellis & Ferre, 1999; Ferre, 2002, 2006). As listening demands increase, the listener may become less tolerant of extraneous distraction. Fatigue may set in and listening attitude may deteriorate with the listener appearing inattentive or confused (Ferre, 2006, 2007). In the assessment process, impaired auditory integration should be differentiated from attention deficit, sensory dysregulation, executive dysfunction, or general anxiety or depression.

Impaired auditory pattern recognition, regardless of response mode (labeling or imitation) as well as excessive left ear suppression on dichotic listening tests suggests a prosodic deficit, a deficiency in using prosodic features of the signal, a predominantly right hemisphere function. Running speech can be conceptualized as a series of acoustic patterns to which specific meaning must be attached for comprehension to occur. As we speak, we often drop word endings and blur perceptual timing boundaries by failing to enunciate clearly (Picheny, Durlach, & Braida, 1985, 1986). In everyday communication, the listener must navigate between and among these rapidly changing acoustic patterns; analyzing, synthesizing, manipulating, and attaching meaning to them quickly and efficiently. A non-impaired listener is able to perceive the *ebb and flow* of these changing patterns in the speech stream and make sense of the signals even when they are disrupted. The listener with prosodic deficit has difficulty recognizing the acoustic contours (i.e., patterns) in the rapidly occurring speech stream and perceiving timing cues in running speech (e.g., pacing, segmentation, and rhythm cues). Prosodic deficit may manifest as inconsistent processing of rapid speech and/or difficulties listening in highly noisy or reverberant environments, when listening to unfamiliar vocabulary, an unfamiliar speaker, or to someone not speaking clearly. The listener may misperceive the intent of the message or perceive one that is very different from that which was spoken, resulting in miscommunication (Bellis, 2003).

Functional challenges may be seen in reading, spelling, direction following, note-taking, attention, working memory, and problem-solving. Ability to recognize and use other types of sensory patterns (e.g., visual and/or tactile) may be impaired. Communication problems of the listener with prosodic deficit can include difficulties in syntactic, semantic, pragmatic, and social language skills, including difficulty understanding sarcasm and recognizing and using nonverbal pragmatic language cues such as facial expressions, body language, and gestures (Bellis, 2006; Bellis & Ferre, 1999; Ferre, 2007).

As noted above, binaural processing, including binaural integration and separation, is a fundamental central auditory skill set. A primary CAPD can impair binaural processing through impaired discrimination, as in the decoding profile; impaired interhemispheric communication, as in the integration profile, or impaired right hemisphere function, as in the prosodic profile. However, poor performance on tests of binaural processing also may result from inefficient *intra*-hemispheric communication; the presumed underlying cause of associative deficit. A secondary central auditory processing test profile, this deficit is characterized by significant auditory-language processing difficulties, believed to be related to dysfunction in the communication between the primary (Heschl's gyrus) and secondary or auditory association (Wernicke's area) cortices of the dominant (usually left) hemisphere (Bellis & Ferre, 1999; Ferre, 2002). On central auditory tests, the ability to recognize degraded speech and temporal patterns is age appropriate with marked difficulty for one or both ears on dichotic listening tasks taxing binaural integration and separation skills. This intra-hemispheric deficit impacts language processing and the listener has difficulty attaching linguistic meaning to incoming acoustic signals quickly and efficiently (i.e., associating the auditory with language). In general, listeners with this auditory-language association deficit don't extract key words from running speech as well as their peers and appear not to *speak the same language* as their peers. The listener tends to take most statements literally and often sees ambiguity even in seemingly straightforward messages (Bellis, 2003, 2006; Bellis & Ferre, 1999; Ferre, 2006). Listening difficulties arise when vocabulary is unfamiliar; information is presented without sufficient contextual or visual cues, or when the message is linguistically ambiguous. Because this deficit is more accurately conceptualized as a language impairment, the daily living challenges for this listener center on issues of comprehension—reading or listening, specific language usage, and social/pragmatic communication (Bellis, 2003, 2006; Bellis & Ferre, 1999; Ferre, 2006).

As noted in the first paragraph of this paper, the "landscape" of CAPD is reflected in the action of the afferent auditory system. However, the "process" of processing is incomplete without considering the listener's ability to execute a response as evidenced by accurate and appropriate verbal or written responses or successful task completion. Certainly, impaired ability to discriminate, analyze, synthesize, and/or attach meaning to an incoming auditory signal can create disability in expression or execution skills. However, performance difficulties (e.g., poor direction following or task completion), may exist in the absence of receptive sensory or linguistic dysfunction. Disruptions associated with impaired expressive skills or difficulty executing a response may manifest on central auditory tests as an output-organization deficit profile. This secondary central auditory processing test profile is characterized by poor scores on tests requiring the reporting of multiple or precisely sequenced targets, with normal performance seen on single target and/or free recall tasks. Atypical crossed reflexes or otoacoustic emissions may be seen (Bellis, 2003). Difficulty in skills needed for information organization or recall may adversely affect planning, applied problem-solving, listening comprehension, direction following, spelling, verbal or written expression, word finding, and retrieval. Behaviorally, the listener may exhibit difficulty hearing in noise, be disorganized, impulsive, or present with issues in executive functioning. Although no specific neurophysiologic region of dysfunction is implicated by test findings, the central auditory test results and behavioral manifestations implicate the frontal and prefrontal cortices or efferent (i.e., motor) pathways as possible sites of dysfunction (Bellis, 2006; Bellis & Ferre, 1999; Ferre, 2002; Richard, 2001).

Central auditory processing profiles can occur singly or in combination, although one profile typically predominates. It is important to note that if the listener exhibits deficits in all auditory processes assessed or test results suggest the presence of more than two of the five functional deficit profiles, consideration should be given to the likelihood of global, higher-order, or bi-hemispheric dysfunction as the primary condition underlying reported or observed listening, language, or learning difficulties. In these cases, diagnosis of CAPD is not appropriate and referral should be made to related professionals (e.g., neuropsychology, neurology, and speech-language pathology) for additional assessment.

Although often overlooked, intervention for CAPD is an integral part of the audiologist's role and responsibilities. A detailed discussion of specific intervention strategies is not within the scope of this paper. However, key points regarding intervention deserve a brief mention:

- Differential intervention is a balance of deficit-specific management and treatment strategies that derive logically from diagnostic test results and have solid neuroscientific foundations.
- Effective intervention is timely and collaborative and includes treatment goals that are measurable, functional, and consistent with the neurodevelopmental hierarchy of auditory and communicative-cognitive function.
- In treatment, formal and informal therapy techniques are used to reduce or resolve auditory deficits and to teach functional compensatory strategies. In management, compensatory strategies and environmental accommodations are implemented to minimize the impact of the disorder on the listener's day-to-day functioning.
- There is no *silver bullet* for treating CAPD. A program that may be effective for one listener may be ineffective for another based on the specific auditory skills affected and the impact of the disorder on the listener's life. Before implementing any treatment program, the audiologist should verify the specific needs of the listener with CAPD in the classroom, workplace, and at home. In addition, the nature of the processing deficit

should be described as fully as possible, as not all treatment programs may be beneficial for all types of CAPD.

- Regardless of type of deficit and functional sequelae, treatment for CAPD typically includes both bottom-up therapy, designed to reduce the deficit, and top-down therapy, designed to minimize residual effects of the disorder (ASHA, 2005; Chermak & Musiek, 1997; Bellis, 2003; Ferre, 2002).
- Auditory skill development as well as success of recommended treatment and/or management strategies, or lack thereof, should be documented at periodic intervals and adjusted as needed to meet the listener's functional needs.

Central auditory processing disorder (CAPD) can affect adversely academic achievement, speaking and listening, life skills, and sense of self. Differential diagnosis of CAPD and related, often co-morbid disorders leads to differential intervention. In differential diagnosis, formal and informal assessment results are interpreted in order to clarify the nature of the deficit that affects a listener's life. In differential intervention, deficit-specific recommendations for management and treatment are developed that create positive outcomes for our clients.

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