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Clinical Practice Guidelines

Diagnosis, Treatment and Management of Children and Adults with Central Auditory Processing Disorder

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EXECUTIVE SUMMARY

The following clinical practice guidelines provide evidence-based recommendations for the diagnosis, treatment, and management of children and adults with (central) auditory processing disorder ([C])APD). The American Academy of Audiology (AAA) appointed a task force to develop a document to provide direction to clinicians involved in this practice area, as well as to provide a resource to the AAA and its membership for communication with the public. This document was to build on and expand prior statements and reports on (C)APD issued by other professional associations (e.g., ASHA, 2005b) and consensus panels (e.g., Jerger & Musiek, 2000). The present guidelines focus on four major areas of (C)APD: 1) patient history and selection criteria, 2) diagnosis, 3) intervention, and 4) professional issues, education, and training. The guidelines emphasize the following points and contain the following recommendations.

(C)APD is seen in a wide array of populations, including children and adults. It can be the result of a number of different etiologies that involve deficits in the function of the central auditory nervous system (CANS). Neurological involvement ranging from degenerative diseases to exposure to neurotoxic substances can result in (C)APD. In addition, developmental, communicative, and learning-related problems, as well as peripheral hearing loss and aging processes, can impact central auditory processing. A substantial number of individuals seen for (C)APD evaluations are children and adults with disorders of auditory processing due to diffuse central nervous system (CNS) dysfunction but with no identifiable lesions. These individuals often have difficulties with language, learning, and reading in addition to their auditory deficits. In questioning the patient or informant, it is essential that the clinician consider a range of issues, including hearing, medical, educational, social, developmental, and communicative status. A comprehensive history often reveals potential comorbid conditions that may affect test performance and the interpretation of the test results. It also ensures the selection of diagnostic tests most appropriate to the individual's profile and most likely to provide valid and reliable information leading to accurate diagnosis. Patient factors and considerations include: age, cognitive ability, general behavior, speech, language and hearing status, motivation, and attention issues. An in-depth, relevant history and careful test selection process will maximize the power of the diagnostic test battery.

The purposes of central auditory testing are two-fold: (1) to identify the presence of abnormalities in or dysfunction of the CANS and diagnose (C)APD, and (2)to describe the nature and extent of the disorder for purposes of developing management and intervention programs for affected individuals. Accurate diagnosis is dependent on the administration and interpretation of sensitive, efficient, and well-normed behavioral and electrophysiologic measures of central auditory function. Given the complexity and redundancy of the central auditory system, accurate diagnosis typically requires the administration of more than one test; however, while sensitivity may be improved by increasing the number of tests in the battery, the administration of too many central auditory tests may compromise specificity. The clinician should select normed tests that provide insights regarding the presence of (C)APD, assessment of various central auditory processes and behaviors, and evaluation of the integrity of the CANS at multiple sites and levels. Tests that have been shown to be sensitive and specific to known involvement of the CANS (e.g., through lesion studies, brain imaging, and other methods) provide guidance regarding the integrity of the various auditory processes and the CANS. Tests should be selected that have appropriate normative data. No matter how efficient a test may prove to be, it is of no clinical utility if appropriate norms are not available.

Intervention for (C)APD has received much attention recently due to advances in neuroscience demonstrating the key role of auditory plasticity in producing behavioral change through intensive training. With the documented potential of a variety of auditory training procedures to enhance auditory processes, the opportunity now exists to change the brain, and in turn, the individual's auditory behavior through a variety of multidisciplinary approaches that target specific auditory deficits. Customizing therapy to meet the client's profile (e.g., age, cognition, language, intellectual capacity, comorbid conditions) and functional deficits typically involves a combination of bottom-up and top-down approaches.

In addition to auditory training, the management of acoustic conditions (e.g., classroom acoustics) and signals (e.g., through high fidelity listening devices), coupled with educational, cognitive, language, metacognitive, and metalinguistic strategies can serve to reduce auditory deficits and lead to more effective listening, communication, and learning.

While there has been significant progress in professional education and training in (C)APD, as evidenced by the increasing number of conference presentations, published articles, and professional association reports on this topic, there remains a documented need for additional improvements in this area at the graduate education level and through continuing education. In particular, additional course work in the basic sciences will provide clinicians with the knowledge needed to critically apply diagnostic tools and treatment strategies.

Among the most pressing professional issues is the lack of intensive treatment provided in schools. Ironically, although large numbers of individuals with (C)APD are children in schools, current school policies and caseloads do not support the intensive training required for cortical reorganization and behavioral change. Because (C)APD is often a multifaceted problem, a team approach is needed to best serve the individual and his/her family. (C)APD must be diagnosed by an audiologist; however, other professionals can and should be involved in the broad assessment of the functional deficits experienced by the individual with (C)APD and in planning the intervention activities needed to minimize those deficits. Reimbursement is another pressing professional issue. Despite improved reimbursement rates for some diagnostic services, the rates remain inadequate, and clinicians cannot use some current procedural terminology (CPT) codes with certain third party payers (e.g., Medicare) to secure reimbursement for their intervention efforts. The AAA and other professional associations representing audiologists must continue their efforts to educate physicians, teachers, parents, and legislators and their staffers to the level of education, training, instrumentation, and clinical time needed for the accurate and early diagnosis and multidisciplinary assessment of (CAPD) and its intervention. The support and advocacy of these professional associations may lead to smaller caseloads and more therapy time per child in schools, as well as positive changes in reimbursement rates.

These guidelines are not exhaustive and are not intended to serve as the sole source of guidance for the clinician, nor are they intended to replace clinical judgment. Rather these guidelines reflect the best evidence-based practices in this area at this time as judged by the members of this task force. They should be used as a framework to guide the clinician in decision-making and best clinical practices as they relate to the diagnosis and treatment of (C)APD in various clinical populations presenting with this disorder.

INTRODUCTION

The following clinical practice guidelines for (central) auditory processing disorder [(C)APD] were developed by a task force appointed by the American Academy of Audiology (AAA). The nine-member task force included experts from various academic and clinical settings with extensive clinical and research experience and knowledge of (C)APD, representing varied philosophies and multiple perspectives. The document is written primarily for clinicians. However, the guidelines are not intended to be an exhaustive treatise on (C)APD, but rather to serve as a practical directive for those serving individuals with this disorder. Despite the strong research base underlying central auditory processing and its disorders, continued research is needed to improve our understanding of this disorder and the efficacy of the clinical services provided to individuals with (C)APD and their families. Although not the primary focus of this task force report, comments regarding research needs can be found at the end of each major section of these guidelines.

Included in this introduction is the definition of (C)APD that framed the task force's work, as well as definitions of related terms and conventions adopted by the task force for consistency across the document. An overview of the guidelines also is provided.

The definition of the term, central auditory processing disorder, has evolved over the years (see ASHA, 1996, 2005b; Jerger, 1998; Jerger & Musiek, 2000). This document builds on the ASHA 2005 definition, which states that "(C)APD refers to difficulties in the perceptual processing of auditory information in the central nervous system and the neurobiologic activity that underlies that processing and gives rise to the electrophysiologic auditory potentials." While controversial issues remain in this clinical practice area (as does in most others), several lines of evidence have accumulated over the last 50 years definitively establishing (C)APD as a "true" clinical disorder and documenting the strong link between well-defined lesions of the central auditory nervous system (CANS) and deficits on behavioral and electrophysiologic central auditory measures (Boscariol et al., 2009; Boscariol et al., 2010). Perhaps the most obvious example are cases of complete central deafness, in which individuals show pronounced auditory deficits due to lesions existing primarily in the auditory regions of the brain, despite the presence of normal peripheral systems (Griffiths, 2002; Musiek, Baran, Shinn, Guenette, Zaidan, & Weihing, 2007; Musiek & Lee, 1998). While there is considerable overlap and imprecise use of terms—including central deafness, cortical deafness, word deafness, and auditory agnosia— central deafness may define the more fundamental disorder. Word deafness rarely exists without some degree of impaired discrimination or recognition of non-verbal stimuli (Musiek et al., 2007) and some have argued that auditory agnosia (the inability to recognize categories of sound) may evolve from central deafness (Griffiths, 2002). Studies also have shown congruent relationships among subjective complaints, central auditory test findings, and functional imaging results (e.g., Hugdahl, Heiervang, Ersland, Lundervold, Steinmetz, & Smievoll, 2003; Moncrieff, McColl, & Black, 2008).

(C)APD affects both children and adults, including the elderly. Diagnosis of (C)APD should be made on the basis of a carefully selected battery of sensitive and specific behavioral tests and electrophysiologic procedures, supplemented by observation and detailed case history. The diagnosis should be made by audiologists who have been properly educated and trained in the area of (C)APD, including the administration and interpretation of these tests and procedures. Acoustic control of both the test stimuli and the testing environment is essential, and at times special equipment is necessary to diagnose (C)APD. Multidisciplinary assessment complements audiologic diagnosis by revealing functional deficits associated with the (C)APD, identifying comorbid conditions, and informing intervention plans. Likewise, intervention typically requires a multidisciplinary team given the potential impact of (C)APD on listening, communication, academic success, job performance, and social function, as well as the frequent comorbidity of this disorder with related language, learning, and cognitive disorders.

While recognizing that different terms are used in different clinical and research settings to refer to individuals diagnosed with (C)APD (e.g., patient, client, student, subject, participant), the term, individual, is used for consistency in this document when referring to a child or adult diagnosed with (C)APD, unless doing so results in an awkward construction. In contrast, the terms, audiologist and clinician, are both used in the document acknowledging that not all professionals active in the area of (C)APD are audiologists.

The term, diagnosis, refers to the identification and categorization of impairment or dysfunction, often providing a description of auditory strengths and weaknesses. In contrast, the term, assessment, refers to the formal and informal procedures used to collect data and gather evidence regarding the functional impact of the impairment or dysfunction for purposes of identifying comorbid conditions and planning and implementing intervention. While (C)APD is an audiologic diagnosis, assessment of individuals diagnosed with (C)APD typically involves a multidisciplinary team, often including audiologists, speech-language pathologists, psychologists, educators, and physicians.

Sensitivity is a measure of a test's hit rate (i.e., true positives) or yield of abnormal results when in fact the individual tested does have the deficit for which the test probes. Specificity is a measure of a test's correct rejection rate (i.e., true negatives) or yield of normal findings when the individual is normal along the parameters being assessed. Specificity is related to the term, false positive, in that the false positive rate is defined as 1 minus the specificity (e.g., 1 – 80% specificity = 20% false positive rate). Test efficiency is the combination of specificity and sensitivity; that is, the overall number of true positives and true negatives divided by the total number of individuals tested. Validity is the degree to which evidence and theory support the interpretations of the text scores entailed by the proposed uses of the tests; that is, the degree to which the test measures what it purports to measure. Reliability, which refers to the stability of a test score, is essential to validity.

Management, intervention, and treatment are commonly used terms associated with the habilitation or rehabilitation of persons affected by (C)APD and other disorders. The terms are defined as follows for purposes of this document. Intervention is an encompassing term referring to one or more actions taken in order to produce an effect and alter the course of a disease, disorder, or pathological condition. Treatment is any specific procedure used to prevent, remediate (i.e., cure), or ameliorate a disease, disorder, or pathological condition. Management refers to compensatory approaches (e.g., strategies, technologies) used to reduce the impact of deficits that are resistant to remediation.

The clinical practice guidelines discussed in this document provide evidence-based recommendations for diagnosis and intervention. Within each section of this report, the level of evidence supporting a particular practice recommendation is provided. The level of evidence scale utilized for this purpose is numerical, ranging from 1 to 5, with 1 indicating the strongest level of support and 5 the weakest. While the level of evidence approach is useful, it should be understood that this model was developed primarily for biostatistical treatments and epidemiologic studies, a somewhat different context than most studies relevant to audiology. Moreover, the model rates group studies as superior to individual case studies; however, this does not account for the fact that the results of group studies reflect “average” performance and might not directly apply to any particular individual. In fact, case studies and retrospective studies (which are classified as level 3 or 4 evidence) can often provide clinicians with evidence appropriate for a particular individual’s profile and intervention (Barlow & Hersen, 1984). Clinicians should take a pragmatic approach to evaluating evidence in that they should neither dismiss evidence simply because it is “weaker,” nor automatically accept evidence as infallible simply because it is assigned a higher numerical rating. The evidence-based recommendations in these guidelines conform to this rating rubric to provide the reader some direction for current practice and future research. Description of the various levels of evidence can be found in Appendix A.

The guidelines presented in this document focus on four major areas. These include: 1) patient history and selection criteria, 2) diagnosis, 3) intervention, and 4) professional issues, education, and training.

PATIENT HISTORY AND SELECTION CRITERIA

(C)APD is a disorder of the central auditory nervous system (CANS) that is associated with a number of behavioral manifestations and a variety of symptoms, some of which may be quite subtle. The processing of auditory information within the central nervous system is quite complex, involving both serial and parallel processing within the auditory structures of the CANS itself, as well as shared processing with other sensory and/or higher order brain structures and systems (e.g., language, attention, and executive control). Given the organization of the central nervous system and the nature of processing, the behaviors, symptoms, and levels of impairment observed in individuals with (C)APD are often quite diverse and are by no means homogenous. Since the brain is non-modular, with many regions responsible for the processing of information from multiple sensory systems as well as higher order cognitive (e.g., attention, memory, etc.) and language functions (Ghazanfar & Schroeder, 2006), the behaviors and symptoms noted in individuals with (C)APD often overlap with those that are observed in individuals with other sensory and/or cognitive disorders. For these reasons, a multidisciplinary approach to assessment of the individual at-risk for (C)APD is an important complement to the audiologic diagnosis of (C)APD (ASHA, 2005b; Baran, 2007; Bellis, 2003, 2007; Chermak, 2007; Chermak & Musiek, 1997; Ghazanfar & Schroeder, 2006: Hurley & Hurley, 2007; Musiek & Baran, 2007, Musiek, Bellis, & Chermak, 2005). (Levels of evidence: 2, 3, 4, 5).

A carefully elicited case history provides the audiologist with important information about the likelihood of CANS compromise, including the potential site(s) of the compromise within the CANS (e.g., brainstem, cortical, corpus callosum, etc.). The case history also provides the audiologist with information regarding the individual's functional auditory and related complaints. Such information helps guide the selection of the specific behavioral tests and/or electrophysiologic procedures that should be included in a test battery for the evaluation and ultimate diagnosis of (C)APD. The case history also helps the audiologist recognize (1) the existence of any potential comorbid sensory deficits and/or conditions, which if present may necessitate the use of a modified test battery, and (2) the need to consider the presence of the comorbid condition or conditions in the interpretation of test results (ASHA, 2005b; Baran, 2007; Musiek, Baran, & Pinheiro, 1994).

Case History Guidelines:

A carefully elicited comprehensive case history is essential to both diagnosis and intervention. (C)APD has been linked to a number of different etiological bases, including frank neurological lesions or compromise of the CANS, such as in neoplasms, degenerative processes (e.g., multiple sclerosis), seizure disorders (e.g., Landau Kleffner Syndrome), head trauma, cerebrovascular accidents, and metabolic disorders, as well as benign CANS dysfunction, such as cerebromorphological abnormalities, neuromaturational delays in the development of the CANS, often secondary to auditory deprivation, and age-related changes in CANS function (Bamiou, Musiek & Luxon, 2001; Baran & Musiek, 1999; Musiek, Baran, & Pinheiro, 1994; Musiek, Gollegly, & Baran, 1984). A substantial number of individuals seen for (C)APD evaluation are children and adults with auditory-related complaints but with no identifiable lesions of the CANS and no apparent prenatal or perinatal disease, injury, or exposure related explanation for their (C)APD. These individuals often present with difficulties in listening, language, learning, reading, and in other academic and social areas. For all of these individuals, however, information obtained from the case history can help uncover the potential etiological basis for the disorder, as well as the functional impact of the disorder on the individual's communicative, vocational, and/or academic performance. (Levels of evidence: 2, 3, 4, 5).

Specific areas that should be probed during the case history interview include the following:

- auditory and/or communication difficulties experienced by the individual
- family history of hearing loss and/or central auditory processing deficits
- medical history, including birth, otologic and neurologic history, general health history, and medications
- speech and language development and behaviors
- educational history and/or work history
- existence of any known comorbid conditions, including cognitive, intellectual, and/or medical disorders
- social development
- linguistic and cultural background

- prior and/or current therapy for any cognitive, linguistic, or sensory disorder or disability. (Levels of evidence: 4, 5).

Case history information can be obtained through standard clinical interview procedures and may involve interviewing the patient, his/her parents or other family members, or another informant who is responsible for the patient. In addition, a review of available medical, educational, and clinical records can help to further elucidate the nature of the problems or difficulties that the individual is experiencing. It can also serve to document the presence or absence of any comorbid condition(s) that the individual may be experiencing and thereby help inform professional decisions regarding: (1) the need to modify diagnostic test procedures or protocols, (2) the need to refer for follow-up cognitive, speech and language, educational, and/or behavioral testing, and (3) the need to consider modifications to the intervention plan if a (C)APD is identified and the individual is also experiencing a comorbid condition or conditions.

Ancillary information can also be gained through direct observation of the individual's behaviors during the interview itself or in some other context (e.g., the classroom, the home, the work setting, etc.). Completion of behavioral inventories and/or checklists by a parent, teacher, employer, spouse or significant other, or the individual himself/herself also provides useful insights into functional deficits, diagnostic test selection, and intervention priorities.

Self-assessment tools and/or behavioral checklists completed by individuals familiar with the individual can provide the audiologist with important insights into the individual's specific auditory deficits and the functional impact of these deficits on the individual's communication, academic or workplace performance, his/her family and social interactions and activities, etc. There are a number of instruments that can be used for this purpose. Some have been developed specifically for use with individuals who may be at-risk for (C)APD, whereas others are more generic, but probe behaviors and symptoms that provide some insights into the potential of a (C)APD (Anderson & Matkin, 1996; Anderson & Smaldino, 1998, 2000; Geffner & Ross-Swain, 2006; Kelly, 1995; O'Hara, 2007; Schow, Chermak, Seikel, Brockett, & Whitaker, 2006; Smoski, Brunt, & Tannahill, 1992; Willeford & Burleigh, 1985).

Direct observation of the individual at-risk for (C)APD can provide additional information about the individual's auditory behaviors and difficulties. The audiologist can gain invaluable insights during the interview process as well as throughout the diagnostic process by carefully observing the individual's behavior during these activities (e.g., How does the individual respond to questions, directions, etc.?, Are his/her responses quick, delayed, or erratic?, Does he/she appear to be distractible?, Is he/she impulsive? Are there any indications of neurologic compromise, such as abnormal eye movements, gait problems, or arm, leg, and/or facial paralysis or weakness?).

Although more difficult to arrange, the direct observation of the individual in a naturalistic setting, such as in school or at work, is potentially more revealing than the observation of the individual in the clinical setting. Direct observation complements and supplements the case history interview and may allow the audiologist the opportunity to uncover the answers to other important questions (e.g., How does the individual perform in group settings?, What are the effects of the apparent auditory problems on the individual's communication abilities?, How does behavior change in noise?, Are there unique listening situations that pose particular problems for the individual?, Is the individual an accurate reporter of the difficulties that he or she is experiencing, or does the individual tend to exaggerate, overstate, or understate the extent of these difficulties?). The answers to these types of questions can inform the audiologist's selection of tests for inclusion in the test battery, and will also provide a solid foundation for intervention planning should the individual ultimately be diagnosed with a (C)APD (see Baran, 2007, for discussion).

In the likely event that the audiologist will be unable to personally observe the individual outside of the clinical setting, the audiologist may be able to obtain the answers to some of these questions by interviewing the parents, spouse, and/or significant others who may accompany the individual to the diagnostic session. This can be accomplished either through direct face-to-face interviewing procedures during the diagnostic session or by requesting completion of one or more of the behavioral checklists mentioned above either during the diagnostic appointment or outside of the appointment. The audiologist may also find it helpful to develop his/her own observational checklist as this may provide for a more directed and targeted observation, and in turn, the documentation of the behaviors of interest.

Common behavioral manifestations and symptoms that are reported and/or observed during interviewing or observation include, but are not limited to the following:

- difficulty understanding speech in the presence of competing background noise or in reverberant acoustic environments
- problems with the ability to localize the source of a signal
- difficulty hearing on the phone
- inconsistent or inappropriate responses to requests for information
- difficulty following rapid speech
- frequent requests for repetition and/or rephrasing of information
- difficulty following directions
- difficulty or inability to detect the subtle changes in prosody that underlie humor and sarcasm
- difficulty learning a foreign language or novel speech materials, especially technical language
- difficulty maintaining attention
- a tendency to be easily distracted
- poor singing, musical ability, and/or appreciation of music
- academic difficulties, including reading, spelling and/or learning problems

Often the report and/or observation of these types of behaviors may be more revealing of the true functional impact of the (C)APD on the individual's daily life than the specific results of the diagnostic testing (ASHA, 2005b; Baran, 2007; Bellis, 2003; Chermak & Musiek, 1997). Since (C)APD involves many processes that are mediated at different levels of the CANS, it is unlikely that an individual will present with all of these behaviors or characteristics. Also, since there is considerable overlap in the behaviors or characteristics outlined above with those that are often associated with other cognitive, linguistic, or behavioral disorders, the manifestation of one or more of these behaviors does not necessarily indicate that the individual has a (C)APD. Many, if not most, of these behavioral manifestations and characteristics are not unique to individuals with (C)APD. These symptoms and/or behaviors may be attributable to another disorder or condition that may either be the etiological basis for the individual's condition or which may coexist with (C)APD; therefore, the presence of one or more of these behaviors should only place the individual at-risk for (C)APD and not be treated as a definitive diagnostic indicator of (C)APD. (Levels of evidence: 4, 5).

Patient Selection Guidelines:

A carefully elicited case history includes information about the patient that should guide the selection of a test battery and influence the interpretation of test results. Factors such as age, cognition, intelligence, attention, motivation, memory, language function, peripheral hearing loss and linguistic background can confound test results if these factors are not considered when determining candidacy for evaluation, test selection, and interpretation of test results.

Age Considerations

Age is a primary consideration in the evaluation of children. Interpretation of results of behavioral measures of central auditory function in children under age 7 years (developmental age) is difficult (ASHA, 2005b; Jerger & Musiek, 2000). Normative data for behavioral measures of central auditory functioning are often limited or not available secondary to task complexity, maturational variability of the CANS (Yakovlev & Lecours, 1967), and the response demands of the task (see Baran & Musiek, 1999; Bellis, 2003). Similarly, many electrophysiologic measures of central auditory function yield variable results in children under 10 years of age secondary to the maturational time course of the CANS (ASHA, 2005b); therefore, the use of both behavioral and electrophysiologic assessment procedures requires a thorough understanding of the effects of maturation of the CANS on the test results (Baran, 2007; Hall, 2007). (Levels of evidence 3, 4, 5).

A limited number of behavioral auditory measures have been developed for use with younger children (e.g., Pediatric Speech Intelligibility Test [PSI; Jerger & Jerger, 1984]; SCAN-3:C Tests for Auditory Processing Disorders in Children [Keith, 2009b]; Staggered Spondaic Word Test [SSW; Katz, 1962]). Use of measures such as these, coupled with available behavioral checklists as discussed above, can provide insight into children who may be “at-risk” for (C)APD, leading to recommendations for close monitoring of skills, enrichment activities designed to develop and augment auditory skills (see intervention section), and regular follow-up to determine the appropriate diagnosis as early as possible (see Baran, 2007). However, behavioral checklists, screening measures, and/or single test assessments do not constitute a comprehensive diagnostic battery that assesses a variety of auditory processing skills (Jerger & Musiek, 2000). Therefore, a definitive diagnosis of (C)APD should be withheld until a comprehensive, age-appropriate, and efficient test battery can be completed.

Cognitive Abilities

The individual’s mental age and cognitive status (including IQ) can influence the individual’s ability to complete complex behavioral measures of auditory function, making accurate interpretation of results difficult and, in some cases, rendering the test results invalid. In cases of questionable cognitive function or intelligence, the need for multidisciplinary assessment becomes imperative. Results of cognitive, neuropsychological, psychoeducational and speech-language assessments will provide valuable information to help determine whether it is prudent to proceed with the central auditory processing evaluation, and if so, how the results of these other evaluations can influence interpretation of the central auditory processing test results (ASHA, 2005b). In cases where critical assessment data are not available and a significant cognitive, intellectual, or speech and language deficit is suspected, a referral to another professional (e.g., psychologist, speech-language pathologist, neuropsychologist) for assessment may be warranted before a central auditory assessment is undertaken.

There will be some young children and individuals with developmental delay or acquired brain injury who may not be able to complete behavioral testing due to a limited capacity to meet the language, memory and/or attention demands of the available tests (Baran, 2007; Bellis, 2003, Chermak & Musiek, 1997). Similarly, elderly individuals may present with decreased memory or attention, which can negatively impact performance on measures of central auditory function (Hällgren, Larsby, Lyxell, & Arlinger, 2001). In some cases, it may be possible to modify test procedures; however, it is important that the audiologist understand how these modifications may impact test interpretation as virtually all of the central auditory tests available for clinical use have been normed on individuals with normal intelligence and cognitive function (see Baran, 2007; Bellis 2007). Many comorbid conditions, such as such as attention deficit hyperactivity disorder (ADHD), anxiety disorder, and depression, which may affect attention can also affect motivation. The audiologist must recognize the potential negative impact of such disorders on auditory performance and strive to ensure that the diagnostic session provides for assessment of multiple auditory processes while carefully monitoring the individual's state (see Chermak, 2007). Modified procedures and use of reinforcement or other methods of maintaining attention and motivation are often required when testing those with comorbid conditions. Finally, in cases where medication has been prescribed for attention, anxiety or other cognitive disorders, testing should be completed while the patient is on his/her prescribed medication when diagnosis of central auditory dysfunction is the goal of the evaluation (Chermak, Hall, & Musiek, 1999). However, there may be situations in which the clinician desires to test the individual in an unmedicated state for other purposes, such as when evaluating effects of medication on auditory behaviors for purposes of differential diagnosis.

Language Status and Proficiency

It is important to consider the language background and level of language function of the individual referred for evaluation. Many behavioral measures of central auditory function use verbal stimuli and require a verbal response. Behavioral and some electrophysiologic measures require the ability to understand the test instructions. It is therefore important to ensure that the individual has adequate receptive and expressive language skills to complete the tasks within the test battery (see Baran & Musiek, 1999; Richard, 2007).

Non-native English speakers or those with limited proficiency in English may require a modification of the test battery, which may include a combination of electrophysiologic measures (e.g., the auditory middle and/or late responses) and behavioral tasks using simple verbal stimuli (e.g., dichotic digit tasks) and/or nonverbal stimuli (e.g., frequency and/or duration pattern tasks, gap detection tasks) (ASHA, 2005b; Baran & Musiek, 1999; Bellis, 2003; Musiek & Chermak, 1994). In some cases, central auditory tests have been translated, documented to have adequate sensitivity and specificity and normed in the native language of the individual being tested. If such tests are available and the audiologist is able to instruct the individual and interpret his/her responses, then use of these alternative, language-specific tests may be appropriate. In other cases, however, the presence of a significant language delay, disorder or difference will preclude the reliable administration of a test battery or will severely limit the types of procedures that can be employed, thus making it difficult if not impossible to render an accurate diagnosis of (C)APD.

One approach for ruling out linguistic confounds in assessment and analysis of (C)APD test findings is to present the stimuli in an undistorted or non-competing condition (e.g., monotically, unfiltered, temporally intact) as well as in the specific test condition (e.g., dichotically, filtered, or time-compressed). If a deficit exists under the acoustically manipulated test condition but not in the un-manipulated condition, then the performance deficit noted in the test condition was most likely due to the acoustic manipulation rather than to a generalized language impairment or other listener-related variable. Similarly, consistent ear effects (i.e., deficits limited to one ear) or hemisphere effects (i.e., deficits arising from one hemisphere), especially in light of symmetrical hearing sensitivity and speech recognition scores, are more likely to reflect processing deficits rather than generalized global test confounds or comorbid conditions that could be expected to affect performance for both ears.

Some authors have advocated for the development of an international test battery (e.g., Hall, 2007), with reliance mostly on non-speech test procedures to facilitate consistency and uniformity in the diagnosis of (C)APD among individuals from diverse linguistic communities. However, the effect of different native languages on auditory processing of both speech and non-speech signals has yet to be fully elucidated. For example, processing of a tonal language such as Mandarin requires different spectro-temporal representations than does a language such as English (Sibatini, 1980).

Native speakers of Japanese may present mixed hemispheric dominance for language functions in contrast to speakers of the vast majority of languages spoken around the world who present left hemisphere dominance for speech and language (Sibatini, 1980). Further, recent research suggests that learning a second language may impact auditory processing for both the native and the second language learned (Weiss & Dempsey, 2008). There is no guarantee that central auditory deficits in these individuals would manifest in both languages in the same manner when using the same types of tests. Perhaps a core international non-speech test battery, augmented with speech-specific tests for the processing demands in the native language of the individual being tested should be considered when assessing individuals from diverse linguistic communities. Unfortunately at this time, a core international non-speech test battery has not been identified and speech-specific tests for processing demands in the native language of the individual being tested either are not available or are quite limited, depending upon the native language of the individual tested.

Speech Intelligibility

Before administering behavioral tasks of central auditory function requiring a verbal response, it is important to assure that the individual has adequate speech production skills so that responses can be accurately interpreted. Individuals with multiple articulation errors resulting in reduced speech intelligibility may not be good candidates for assessment using behavioral techniques employing speech stimuli, i.e., unless a modified response mode can be adopted (e.g., picture pointing response or written response) (Jerger & Musiek, 2000).

Peripheral Hearing Loss

The influences of the peripheral auditory system on central auditory function must be considered to determine whether the individual can be reliably assessed. Multiple studies have demonstrated the potential negative impact of peripheral hearing loss on central auditory test performance (Divenyi & Haupt, 1997; Humes, Coughlin, & Talley, 1996; Musiek, Baran, & Pinheiro, 1990; Musiek, Gollegly, Kibbe, & Verkest-Lenz, 1991; Neijenhuis, Tschur, & Snik, 2004). While those with significant degrees of bilateral hearing loss who exhibit reduced word recognition skills cannot be accurately assessed, those with lesser degrees of loss and good speech recognition abilities may be candidates for assessment using tests that have shown to be less affected by cochlear hearing loss (e.g., dichotic digit tasks, frequency patterning tasks). For example, it is possible to make a statement about CANS function in an individual with mild-to-moderate hearing loss when central auditory processing performance measures are normal. It is also possible to diagnose (C)APD in individuals with hearing loss when certain patterns of performance emerge (e.g., poorer central auditory performance in the normal hearing ear in individuals with unilateral hearing loss, asymmetrical performance on a central test battery in individuals with symmetrical hearing loss, the presence of ear or electrode effects on electrophysiologic test measures in individuals with bilateral symmetrical hearing loss) (see Baran & Musiek, 1999; Musiek & Baran, 1996). Conversely, the lack of a clear discernible pattern of central auditory performance may represent the influences of peripheral hearing loss (e.g., when central test results are depressed bilaterally in an individual with a bilateral, symmetrical hearing loss). In such cases, a definitive diagnosis of (C)APD should be withheld, even though the possibility of a (C)APD may exist.

Candidates for Central Auditory Testing

Evaluation for (C)APD may be indicated for individuals with listening and related complaints (e.g., learning problems, reading problems, or dyslexia, etc.) spanning the age range from young children to elderly adults. Certainly, those persons with normal peripheral hearing sensitivity who exhibit auditory-related symptoms or those with peripheral hearing loss whose difficulties are greater than would be expected for the degree of hearing loss are candidates for central auditory diagnostic testing, as are those who report a significant history of otitis media or other condition that may result in auditory sensory deprivation. In general, those populations with any neurologic disease, disorder, or insult that affects auditory areas of the central nervous system and who exhibit concomitant auditory symptoms are appropriate candidates for central auditory testing, including but not limited to those with a history of hyperbilrubinemia, which has been shown to affect the cochlear nuclei as well as other auditory neurons in the brain (Dublin, 1976); seizure disorders involving the auditory cortex (e.g., Landau Kleffner Syndrome in children; Landau & Kleffner, 1957); multiple sclerosis and other neurodegenerative disease, traumatic brain injury (Bergemalm & Lyxell, 2005); space-occupying lesions; and other neurological conditions affecting the CANS. There also is current concern about CANS dysfunction in military personnel and veterans who have been exposed to combat-related trauma, which has led to a demand for comprehensive diagnostic assessment of their central auditory function (Hoge, McGurk, Thomas, Cox, Engel & Castro, 2008). Finally, it should be recognized that central auditory dysfunction and associated auditory behavioral difficulties may be of particularly high prevalence in the aging population and may be a predictor of success with binaural hearing aids (e.g., Bellis, Nicol, & Kraus, 2000; Bellis & Wilber, 2001; Chmiel & Jerger, 1996; Golding, Carter, Mitchell, & Hood, 2004; Golding, Mitchell, & Cupples, 2005; Jerger, Chmiel, Allen, & Wilson, 1994; Musiek & Baran, 1996; Rodriguez, DiSarno, & Hardiman, 1990; Stach, Spretnjak, & Jerger, 1990).

Screening Measures

Screening measures can be used to identify individuals who are 'at-risk' for (C)APD and should be referred for diagnostic evaluation. While it is more common to find that children with a range of developmental disabilities are often screened for (C)APD, it is important that older adults with hearing complaints or significant case history information (e.g., hearing difficulties despite normal hearing sensitivity, hearing complaints that exceed expectations based on pure tone test results, less than anticipated benefit from amplification in individuals fitted with hearing aids, case history information that suggests possible central nervous system disease/dysfunction, including head injury, cerebrovascular accident, dementia, etc.) be screened as well. Finally, it is important to note that CANS dysfunction is prevalent among older adults and is a component of presbycusis (Gates, Anderson, Feeney, McCurry, & Larson, 2008; Tremblay, Billings, & Rohila, 2004). While a number of questionnaires have been used to screen for (C)APD (Anderson & Matkin, 1996; Anderson & Smaldino, 1998, 2000; Fisher, 1976; Geffner & Ross-Swain, 2006; Kelly, 1995; O'Hara, 2007; Schow et al., 2006; Smoski et al., 1992; Willeford & Burleigh, 1985), they generally have poor specificity, tend to over-refer, and have not been validated. Other instruments, such as the SCAN-C, SCAN-3:A, and SCAN-3:C (Keith, 2000, 2009a,b) and the Differential Screening Test of Processing (Richard & Ferre, 2006), have been used for screening purposes. Additionally, some of the available diagnostic tests with minimal linguistic loading that will be discussed below have been proposed as potential screening procedures (Jerger & Musiek, 2000; Musiek et al., 1991). Further studies are needed to determine the efficiency of currently available screening instruments, including the efficiency of diagnostic tests used for screening purposes, and to develop new screening tools for (C)APD.

Considerations for Additional Research

- Epidemiologic studies to ascertain the prevalence of (C)APD across the lifespan independent of other disorders.
- Epidemiologic studies to establish the comorbidity of (C)APD with other common childhood disorders including ADHD, language impairment, dyslexia and learning disabilities.

DIAGNOSIS

Introduction

Prompted by Dr. Helmet Myklebust's (1954) recognition of the importance of central auditory processing, the first reports of clinical assessment of central auditory dysfunction appeared in the 1950s (e.g., Bocca, Calearo, & Cassinari, 1954). Diagnostic batteries to elucidate (C)APD have been applied clinically since the 1970s. Presently, diagnostic measures of (C)APD fall into two primary categories: behavioral (psychophysical) and electrophysiological. Both categories are addressed below. The definition of (C)APD necessarily guides its diagnosis (and intervention efforts). Since (C)APD is defined as dysfunction within the CANS (ASHA, 2005b; Bellis, 2003; Jerger & Musiek, 2000; Musiek & Chermak, 1997), the test battery used in diagnosis and assessment should include tests known to identify lesions of the CANS (including diffuse lesions) and to define its functional auditory deficits (e.g., listening deficits).

The (C)APD test battery must be administered in an acoustically-controlled environment and in some cases, using specialized equipment, with test results interpreted by a properly educated and trained audiologist. Since audiologists are the professionals who are charged with evaluating hearing and balance (AAA, 2004; ASHA, 2004c, 2005b, 2005c), and auditory processing is a key aspect of hearing, it follows that audiologists are responsible for diagnosing (C)APD.

Minimum Age for Testing

Many behavioral tests of central auditory processing in current clinical use require a minimum developmental age of seven or eight years, or a level of cognitive functioning that is consistent with this age range. This is particularly true for most behavioral tests involving interhemispheric (corpus callosum) function, as the maturational time-course of this region of the brain is highly variable in children, especially young children below the age of seven or eight years (e.g., Musiek et al., 1984). As such, normative ranges for the majority of behavioral tests in very young children have limited clinical utility due to very large standard deviations and resultant floor or chance effects. Therefore, for children younger than seven or eight years of age, behavioral diagnostic testing for (C)APD should be undertaken with extreme caution. As noted previously, assessment of (C)APD in very young children may include the use of screening measures and behavioral checklists that provide insight into children who may be “at-risk” for (C)APD and a recommendation for close monitoring of skills and regular follow-up to reach a diagnosis as early as possible (see Baran, 2007).

Use of Speech versus Non-Speech Test Stimuli

Behavioral (psychophysical) tests of central auditory function may be categorized as speech or non-speech (i.e., verbal and non-verbal) tests. Within each of these categories, test procedures can be distinguished further based on differential sensitivity and specificity for the evaluation of specific auditory processes and mechanisms. There has been an increased focus in recent years on the need to utilize non-speech tasks in the identification of central auditory dysfunction, mostly to minimize the confounding influence of language on an individual’s performance (e.g., BSA, 2007; Hall, 2007; Moore, 2006). However, speech tasks remain an important component of the (C)APD test battery, as CANS deficits are often apparent for speech (versus non-speech) signals in children and adults on both psychophysical and electrophysiologic measures. It is likely that speech signals provide access to different processing mechanisms in the CANS than do non-speech signals and that the processing of speech signals may be more vulnerable to disruption by CANS dysfunction, resulting in atypical neurophysiologic responses and/or hemispheric asymmetries in CANS function that are apparent for speech signals, but not for non-speech signals (e.g., Bellis et al., 2000; Jerger, Alford, Lew, Rivera, & Chmiel, 1995; Jerger, Moncrieff, Greenwald, Wambacq, & Seipel, 2000; Kraus, McGee, Carrell, Zecker, Nicol, & Koch, 1996; Kraus, McGee, King, Littman, & Nicol, 1994; Phillips & Farmer, 1990; Song, Banai, Russo, & Kraus, 2006; Wible, Nicol, & Kraus, 2005). (Levels of evidence: 2, 3).

Efficiency and Test Performance

Audiologists, related professionals, and clinical scientists generally agree that some of the tests for (C)APD in current clinical use lack rigorous psychometric design, construction, and validation. Populations “suspected” or “presumed” to have (C)APD (e.g., those with learning disabilities, reading problems, or attention deficits) cannot be used to determine validity, efficiency, or clinical norms for diagnostic tests of central auditory processing (Cacace & McFarland, 2005; Musiek et al., 2005). Similarly, speech-language, psychological, and other tests cannot be used to diagnose (C)APD, even if the term "auditory processing" is included in their titles or subtest descriptions. Although populations with learning or related disorders often exhibit listening difficulties similar to those of children and adults with (C)APD, one cannot be sure that the listening problems exhibited in these populations are due to deficits or dysfunction in the CANS (e.g., see Singer, Hurley, & Preece, 1998; Vanniasegaram, Cohen, & Rosen, 2004). Concerns have been raised regarding the utility of tests normed on groups suspected of having (C)APD for the identification of dysfunction of the central auditory pathways, with several clinical researchers arguing that their utility is limited at best (Cacace & McFarland, 2005; Musiek et al., 2005). In contrast, a number of behavioral and electrophysiologic tests exist that have been shown to have validity and efficiency for diagnosis of central auditory dysfunction in patient populations with documented lesions of the CANS (e.g., Aharonson, Furst, Levine, Chaigrecht, & Korczyn, 1998; Bamiou, Musiek, Stow et al., 2006; Baran, Musiek, & Reeves, 1986; Cranford, Stream, Rye, & Slade, 1982; de Bode, Sininger, Healy, Mathern, & Zaidel, 2007; Furst, Aharonson, Levine et al., 2000; Jerger & Jerger, 1974, 1975; Karlsson & Rosenhall, 1995; Katz, 1962; Meyers, Roberts, Bayless, Volkert, & Evitts, 2002; Mueller, Beck, & Sedge, 1987; Musiek, 1983; Musiek et al., 1990, 1994; Musiek, Kibbe, & Baran, 1984; Musiek & Pinheiro, 1987; Musiek, Shinn, Jirsa, Bamiou, Baran, & Zaidan, 2005; Musiek, Wilson, & Pinheiro, 1979). Other tests have proven useful in demonstrating auditory difficulties for purposes of designing remediation (e.g., Cameron & Dillon, 2007; Keith, 2009a,b; Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004). Nonetheless, there continues to be a need to develop new and more precise measures of central auditory function with documented validity, reliability, and efficiency, and with appropriate normative data. Clinicians are advised to peruse a test's manual and the published literature to fully evaluate a specific test's utility. (Levels of evidence: 2, 3).

Efforts to develop new clinical measures of (C)APD and refine existing procedures must include systematic assessment of test performance and the implementation of accepted principles of psychometric test construction. Substantial evidence regarding test performance (e.g., reliability, validity, sensitivity, and specificity) is lacking for some of the commonly used tests of central auditory processing. However, there are numerous measures in current clinical use for which appropriate and substantial evidence supporting test validity, efficiency, and related test performance variables are available (e.g., pattern perception tests, dichotic listening tasks, gap detection tests, and middle latency and cortical averaged evoked responses (e.g., Jerger, 1998; Kileny, Paccioretti, & Wilson, 1987; Musiek, 1983; Musiek et al., 1990; Musiek, Charette, Kelly, Lee, & Musiek, 1999; Musiek et al., 2005). (Levels of evidence: 2, 3).

Interpretation of central auditory test performance is guided by criterion referenced scores (known as normative cut-off scores). A primary purpose of testing is to differentiate normal versus abnormal performance. For that purpose, the use of cut-off scores that are based on appropriate normative data can be used. Cut-off scores (e.g., in percent correct, percentiles, or standard scores) are set at performance levels (e.g., ~ -2 standard deviations below the mean) to achieve the best balance between hit rate (sensitivity) and correct rejection rate (specificity) (e.g., Musiek et al., 2005; Shinn & Musiek, 2007; Turner & Hurley, 2009; Spaulding, Plante, & Farinella, 2006). Another important goal of central auditory testing is to describe areas of strength and weakness in auditory performance. Comparison of performance across tests assists the clinician in gauging the relative strengths or weaknesses of the various auditory processes for purposes of identifying intervention goals and targeting therapy.

Most measures of (C)APD were designed, initially, for clinical identification of CANS dysfunction secondary to confirmed pathology, rather than to evaluate auditory processing in young children. Historically, there has been considerable debate as to the appropriate "gold standard" for (C)APD and other disorders (e.g., language) in children (Peña, Spaulding, & Plante, 2006). An accumulating body of research supports the presence of deficit patterns in central auditory test battery performance in children that mirror those of lesion studies in populations with circumscribed disorders of the CANS and correlates with neuroimaging results (e.g., Boscariol et al., 2009; Boscariol et al., 2010; Jerger, Johnson, & Loiselle,1988; Musiek et al., 1984). Similarly, performance patterns are observed on central auditory tests during maturation and aging that reflect the time-course of functional and structural age-related changes in the central nervous system, particularly the corpus callosum, in normal populations (e.g., Bellis & Wilber, 2000). If certain test patterns have been demonstrated to have good sensitivity and specificity in adults with confirmed CANS lesions (e.g., Bamiou et al., 2006; Blaettner, Scherg, & von Cramon, 1989; Musiek, Baran, & Pinheiro, 1990, 1992), then one may presume a high degree of likelihood that the same pattern of test results, when observed in a child or an older adult undergoing testing for central auditory dysfunction, confirms a (C)APD in that child or older adult. As is the clinical standard in many disciplines concerned with brain-behavior relationships (e.g., cognitive neuroscience, neuropsychology), it is appropriate to use an interpretive approach, extrapolating from relationships in individuals with documented CANS involvement to infer CANS dysfunction in pediatric and geriatric performance on similar measures (see Kolb & Whishaw, 2008 and Musiek et al., 2005 for reviews).

An alternate view is that damage to the brain in adults may not be the same as a "developmental disorder" of the CANS in children, given the roles of plasticity and maturation. This alternate view holds that any test is limited to the characteristics of the subjects from whom the data were collected. Consistent with this view, information about a test standardized on a sample of adults with documented brain lesions might not be applicable to children with similar auditory deficits. The alternate view holds that that lesion studies on adult subjects have provided valuable information for understanding and interpreting auditory behavior; however, other tests not standardized on individuals with documented brain lesions may provide important information on functional auditory abilities (e.g., strengths and weaknesses) in affected persons of all ages.

While recognizing the value of tests not standardized on individuals with documented CANS lesions for purposes of assessment and intervention planning, and while an absolute gold standard may never exist due to the heterogeneity of disorders affecting the CANS, it is clear that test efficiency measured on subjects with well-defined lesions of the CANS provides an important guide for establishing the validity of central auditory diagnostic tests (Musiek et al., 2005). Perhaps the strongest evidence supporting this view of brain-behavior relationships, including in children, are recent studies demonstrating CANS dysfunction in children with perisylvian polymicrogyria (Boscariol et al., 2009; Boscariol et al., 2010). The Boscariol reports may offer the strongest evidence to date that structural changes in an area of the brain associated with auditory and language processing can lead to changes in auditory processing and, therefore, in language and learning, as well. Such studies demonstrate the sensitivity and specificity of our current central auditory tests to detect central auditory dysfunction in any population, notwithstanding individual variability due to plasticity and other factors, regardless of age and/or etiology, and including more diffuse CANS involvement. Investigation of auditory evoked responses, especially those elicited by complex (e.g., speech) signals in normal and disordered populations, may offer an additional clinically feasible approach for defining a "gold standard" for (C)APD in children (ASHA, 2005b; Blaettner et al., 1989; Jerger et al., 2000; Kileny et al., 1987; Knight, Hillyard, Woods, & Neville, 1980; Knight, Scabini, Woods, & Clayworth, 1988; Kraus, Özdamar, Hier, & Stein, 1982; Musiek et al., 1999; Shehata-Dieler, Shimizu, Soliman, & Tusa, 1991; and others). (Levels of evidence: 2, 3).

Behavioral Tests

Tests of Specific Auditory Processes

Behavioral test batteries for diagnosis of (C)APD should include both speech and non-speech (non-verbal) tasks that assess different levels and regions of the CANS and a variety of auditory mechanisms or processes (ASHA, 2005b). These procedures may include, but are not limited to, assessment of the following auditory processes: sound localization and lateralization, auditory discrimination, auditory temporal processing, auditory pattern processing, dichotic listening, auditory performance in competing acoustic signals, and auditory performance with degraded acoustic signals. This section highlights tests and procedures with documented sensitivity to the integrity of the CANS. There are several central auditory processes for which sensitive, clinically useful measures are either unavailable or in development (e.g., localization); these are noted in this section as well. Other measures, which are not used to diagnose (C)APD, but may be useful for assessment of functional abilities related to auditory function (e.g., language processing, phonemic analysis, spelling, etc.) are not detailed in this document. (However, the reader is directed to the preceding section of these guidelines and ASHA (2005b) regarding assessment of the cognitive-communicative and language deficits often associated with (C)APD). For in-depth discussion of tests and procedures reviewed here, the reader is referred to Baran and Musiek, 1999, Musiek et al. (1994), and Musiek and Chermak (2007).

Tests of Temporal Processes (e.g., within- and between-channel gap detection, forward and backward masking, temporal pattern perception). The Gaps-in-Noise (GIN) Test (Musiek et al., 2005) is an example of a new clinical temporal resolution (within-channel gap detection) measure that is based on an extensive psychoacoustic literature for gap detection. The GIN test's advantages for clinical application include: low cognitive demand, relative insensitivity to hearing loss at specific frequencies, ease of administration, use of instrumentation available in the typical audiology clinic, and evidence of early maturation of the auditory skill that is assessed by this test rendering it appropriate for young children (age 7 and older) (Shinn, Chermak, & Musiek, 2009). The GIN test has established sensitivity and specificity to various cortical and brainstem lesions (Musiek et al., 2005). Another promising gap detection test, similar to the GIN, tests both within- and between-channel temporal resolution (Griffiths, Dean, Woods, Rees, & Green, 2001). (Levels of evidence: 2, 3). In addition, a procedure that is currently being utilized clinically is the Random Gap Detection Test (Keith, 2000), and a screening gap detection test is included in the SCAN-3:A and SCAN-3C (Keith, 2009a,b).

Temporal sequencing tests also are an important component of the central auditory test battery. Two temporal sequencing measures, with documented sensitivity and specificity, commonly included in clinical assessment of (C)APD are the Frequency (or Pitch) Pattern Sequence Test and the Duration Patterns Test (Musiek et al., 1990; Musiek & Pinheiro, 1987). In addition, the Newcastle Auditory Test Battery (NAB) includes several tests of temporal processing, primarily threshold measures of various frequency and amplitude modulation rates (Griffiths et al., 2001). (Levels of evidence: 2, 3).

Dichotic Listening (Speech) Tests. First developed over 50 years ago (Broadbent, 1954; Kimura, 1961; Katz, 1962), dichotic listening tests have a long and proven record of sensitivity to (C)APD (Musiek et al., 1991; Hurley & Musiek, 1997). Dichotic procedures are clinically feasible and a variety of dichotic tests using varied speech materials are available [e.g., digits (Musiek, 1983), words (Katz, 1962; Meyers et al., 2002), and sentences (Musiek, 1983; Fifer, Jerger, Berlin, Tobey, & Campbell, 1983)]. In addition, a non-speech dichotic procedure developed by Scherg and von Cramon (1986) demonstrated high sensitivity to lesions of the auditory cortex, suggesting that non-speech measures of dichotic listening may be useful complements to the clinical central auditory test battery. (Levels of evidence: 2, 3, 4).

Research on the mechanisms of auditory processing underlying dichotic listening is ongoing, including investigations utilizing functional Magnetic Resonance Imaging (fMRI) and cortical auditory evoked responses (Bayazit, Öniz, Hahn, Güntürkün, & Ozgören, 2009). Although fMRI and to a great extent auditory evoked potentials are not routinely used for clinical diagnosis at this time, they have provided important insights into the neural mechanisms underlying dichotic normal and disordered dichotic perception (Westerhausen, Woerner, Kreuder, Schweiger, Hugdahl, & Wittling, 2006).

Tests of Monaural Low-Redundancy Speech Perception. Among the first tests used to detect central auditory dysfunction in the 1950s were speech procedures made more sensitive by removal of spectral information. Various strategies are employed for reducing the natural redundancy in speech signals, including filtering selected frequencies (e.g., high- or low-pass filtering), time compression of the speech signals (Beasley, Schwimmer, & Rintelmann, 1972; Bornstein, Wilson, & Cambron, 1994; Kurdziel, Noffsinger, & Olsen, 1976; Wilson, Preece, Salamon, Sperry, & Bornstein, 1994), and embedding speech in background noise or verbal competition (Sinha, 1959; Olsen, Noffsinger, & Kurdziel, 1975). The first two of these low-redundancy speech procedures are generally less vulnerable to higher-level confounds than the latter (e.g., Pichora-Fuller, 2003), but language and cognitive status nonetheless may influence results on all of these tests. As a class of tests, however, low-redundancy speech procedures are less sensitive to (C)APD than other measures outlined in this section (Musiek & Baran, 2002). Nonetheless, monaural low-redundancy speech tests are useful in both the diagnosis of (C)APD and in describing functional auditory abilities (e.g., auditory closure) for the purpose of designing intervention programs. (Levels of evidence: 3, 4).

Tests of Localization and Lateralization and other Binaural (Interaction) Functions. Valid and efficient commercially available procedures for assessing localization and lateralization are lacking, despite the rather extensive literature on experimental (laboratory) investigation of these auditory processes. The traditional masking level difference (MLD) procedure is rarely included in clinical central auditory test batteries, perhaps in part because it does not directly assess either localization or lateralization. However, the MLD has been shown to be sensitive to lower-level brainstem dysfunction (Lynn, Gilroy, Taylor, & Leiser, 1981). Tests of localization have been developed in the laboratory, including a test of localization utilizing the precedence effect, which has been shown to be sensitive to disorders affecting the CANS (Cranford, Boose, & Moore, 1990). An additional clinical measure to evaluate spatial aspects of audition has recently been developed (i.e., the Listening in Spatialized Noise- Sentences Test (LISN-S) (Cameron, Brown, Keith, Martin, Watson, & Dillon, 2009; Cameron & Dillon, 2007). (Levels of evidence: 2, 3).

Auditory Discrimination Tests. Auditory discrimination is a basic auditory process which includes discrimination of small differences in one or more of the three fundamental properties of sound: frequency, intensity and duration. Speech-based auditory discrimination tasks include discrimination between syllables or words that differ only in a single phoneme (Kraus, McGee, Sharma, Carrell, & Nicol, 1992). Cranford and colleagues (1982) developed a test of temporal integration and frequency discrimination that demonstrated good clinical utility and diagnostic power. Nonetheless, there is clearly a need for additional well-designed and norm-referenced clinical procedures for evaluating discrimination of speech and non-speech signals. Although none are commercially available in audiology, one can find useful measures in speech-language test batteries [e.g., Minimal Pairs Test (Robbins, Renshaw, Miyamoto, Osberger, & Pope, 1988); Wepman's Auditory Discrimination Test, Wepman & Reynolds, 1986)].

Selection of Behavioral Central Auditory Tests

The concept of a test battery approach and the "cross-check principle" (Jerger & Hayes, 1976) is well established in audiology, (Jerger & Musiek, 2000; Rosenberg ,1972; Musiek & Chermak, 1994). Diagnosis of (C)APD requires the use of a comprehensive test battery that assesses a variety of auditory processes and mechanisms, as well as various regions and levels within the CANS (e.g., ABR to assess brainstem and P300 to assess cortical areas). The tests in the battery should have proven validity and efficiency for identification of CANS dysfunction and for describing auditory behaviors in individuals affected by (C)APD. It should be emphasized, however, that "more" is not necessarily "better," as the test battery's specificity generally decreases as tests are added (Turner, Robinette, & Bauch, 1999). In general, it is advisable to select the minimum number of tests necessary to provide the best overall sensitivity and specificity while, at the same time, assessing a representative sample of the major auditory processes. Test measures should be carefully chosen so that they do not interject listener confounds as discussed above and allow for identification of patterns of auditory deficits for diagnostic and intervention purposes. Despite the overall goal of administering an efficient test battery—both in clinical diagnostic power as well as time—there are often clinical indications for utilizing two or more procedures in the evaluation of a single auditory process; perhaps to corroborate suspect findings or in those clinical situations where evidence from the case history or other test findings suggests that the auditory process of interest represents the individual's major deficit area.

The goal of an efficient behavioral central auditory test battery both in terms of administration time and diagnostic power can be accomplished in 45 to 60 minutes. Extending the central auditory evaluation beyond an hour may result in sacrificed specificity and increased fatigue, attention, and/or motivational confounds (DeLuca, 2005; Pattyn, Neyt, Henderickx, & Soetens, 2008).

In addition to commercially available tests, audiologists can create, manipulate and record verbal and non-verbal stimuli using a number of software programs, including Audacity, which is a free, open source software (Mazzoni, & Dannenberg, 1999) and Adobe's Audition (formerly known as Cool Edit (Syntrillium Software Corporation, 2002). Using these tools, audiologist can construct tasks to probe central auditory function. While these tools significantly increase the potential access to central auditory testing, they should not be used for diagnostic purposes until sufficient research has been conducted establishing their efficiency and clinical utility.

Prior to administration of the central auditory test battery, the individual's peripheral auditory function should be evaluated with the goal of confidently ruling out or confirming middle ear and/or cochlear auditory dysfunction. A suggested test battery for assessment of peripheral auditory function includes:

- Distortion product otoacoustic emissions (DPOAE) with multiple stimulus frequencies per octave from 500 to 8000 Hz and analysis with reference to normative data to detect objectively cochlear (outer hair cell) dysfunction.
- Immittance measures, including tympanometry and acoustic reflexes in uncrossed and crossed stimulus conditions.
- Pure-tone audiometry with air conduction stimuli at the conventional octaves, plus 3000 and 6000 Hz. Bone conduction may not be necessary if findings are normal for DPOAEs and immittance measures.
- Word recognition performance in quiet at a comfortable intensity level using recorded PB word lists.

Auditory Electrophysiological Tests

Auditory evoked responses (AER) from the auditory brainstem response (ABR) through higher level cortical auditory evoked responses have clinical value in the evaluation of (C)APD (Jerger & Musiek, 2000). Auditory evoked responses can be elicited with simple acoustic signals, such as clicks and tone-bursts, and also with more complex (e.g., speech) signals (see McPherson, 1996, for review).

Auditory Brainstem Response (ABR). The value of an ABR elicited with click stimuli for diagnosis of (C)APD is rather limited. Less than one-in-ten children diagnosed with (C)APD using a comprehensive behavioral test battery shows abnormal ABR findings (Hall & Mueller, 1997; Hall & Johnston, 2007). Though the ABR usually is normal for children with (C)APD associated with developmental (e.g., learning) problems, it is sensitive and specific for individuals with (C)APD secondary to neurological disorders of the brainstem auditory pathways (Musiek & Lee, 1995). For infants and young children, or any person who cannot be evaluated with behavioral techniques, conventional ABR assessment provides useful information on the integrity of the auditory nerve and brainstem pathways. Individuals suspected of (C)APD who yield ABR abnormalities certainly require otologic and neurologic evaluation and follow-up. One practical advantage of the ABR is the well-documented maturation of the response by about 18 months (when the ABR is elicited with click stimuli). Interpretation of ABR findings is therefore rather straightforward, and does not involve age correction for the majority of children referred for (C)APD assessment. (Level of evidence: 2).

Recent research suggests the potential utility of the speech-evoked ABR in the diagnosis of (C)APD and in documenting the benefits of intervention for (C)APD (Banai, Nicol, Zecker, & Kraus, 2005). With appropriate speech stimuli, the ABR appears to reflect processing of the temporal features of speech, in addition to documenting brainstem activation in response to stimulus onset. Speech-evoked ABR findings may also provide a prognostic indicator of benefit from (C)APD intervention (Johnson, Nicol, & Kraus, 2005; Johnson, Nicol, Zecker, & Kraus, 2007). With additional research and clinical experience using commercially available speech-evoked ABR systems, it is possible that this technique will assume an important role in the electrophysiologic evaluation of (C)APD, including a primary role for evaluation of central auditory processing in young children. (Levels of evidence: 2, 3).

Auditory Middle Latency Response (AMLR). The AMLR is generated within thalamo-cortical pathways, including the primary auditory cortex, and is therefore a logical choice for clinical electrophysiological evaluation of (C)APD. Primary auditory cortex is an essential region of the CANS in auditory processing of speech and non-speech signals. Within the past two decades, studies have begun to define the sensitivity and specificity of the AMLR in the identification of CANS dysfunction (Hall & Johnston, 2007; Japaridze, Shakarishvili, & Kevanishvili, 2002; Kileny et al., 1987; Musiek et al., 1999; Shehata-Dieler et al., 1991; see Hall, 2007, for review). The AMLR can be recorded with conventional ABR systems used by audiologists. The response can be elicited with non-speech (e.g., tone burst) or speech stimuli and detected with as few as two channels (four or five electrodes). The AMLR is affected by age up to approximately 10 years. AMLRs can be obtained in children under 10 years; however, due to maturation, the AMLR does not reach adult values for amplitude, latency, and morphology until approximately this age, although maturational variability may lead to adult values being obtained in some children prior to age 10 years. Furthermore, there are interactions among age and stimulus rate. It is not clear whether the AMLR is characterized by "ear effects," that is, differences in findings for stimulation of the right versus left ears when the response is detected from one electrode condition. An "electrode effect" is seen when one electrode (usually on one side of the head) yields a response significantly different in amplitude or latency than the electrode on the other side. The use of linked inverting electrodes near the ears (earlobe or mastoid) or a non-cephalic (true reference) inverting electrode is likely to minimize ear effects. The typical strategy for AMLR analysis, however, involves comparison of AMLR findings, primarily latency and amplitude, for each non-inverting scalp electrode located over the auditory cortex of each hemisphere. Intra- rather than inter-subject comparisons provide better diagnostic information, based on data that reveals highly similar amplitudes from electrodes placed over each hemisphere in normal subjects (Kileny et al., 1987). Moreover, inter-subject measures yield greater variability across normal subjects than do intra-subject measures (Musiek et al., 1999). With proper consideration of the influences of age (maturation), the AMLR offers an electrophysiologic option that appears to be underutilized at this time for evaluation of central auditory processing in children and adults (Schochat, Musiek, Alonso & Ogata, in press). (Levels of evidence: 2, 3).

Other Cortical Auditory Evoked Responses. There is a growing literature describing many auditory evoked responses with latencies beyond 50 ms elicited with non-speech and speech signals. Those most relevant to clinical assessment of (C)APD include the auditory late response (ALR), which is comprised of the N1 and P2 evoked potentials and the P300 response. The cortical auditory evoked responses reflect the function of sites suspected of dysfunction in the majority of children with (C)APD.

The N1 and P2 potentials have been shown to be significantly reduced in amplitude for temporal lobe lesions, but essentially unaffected by lesions confined to the frontal lobe (Knight et al., 1980). More specifically, these investigators showed that N1 was more sensitive than the P2 to temporal lobe involvement. The N1 response was diminished in amplitude for subjects with lesions of the superior temporal gyrus compared to control subjects and subjects with parietal lobe lesions (Knight et al., 1988). Jirsa and Clontz (1990) and Tonnquist-Uhlén (1996) have shown the N1 and P2 to be sensitive to children with learning problems and related auditory processing problems. (Level of evidence: 2).

Although there are non-auditory contributors to the P300, there is evidence that lesions in the auditory regions of the cortex compromise the P300 in both latency and amplitude (Knight, Scabini, Woods, & Clayworth, 1989; Musiek et al., 1992). The P300 is sensitive to compromise of the CANS, specifically to temporal lobe seizure disorder (Soysal, Atakli, Atay, Altintas, Baybas, & Arpaci, 1999). Adults with (C)APD showed significantly longer P300 latencies than normally hearing controls in competing noise conditions (Krishnamurti, 2001). Jirsa and Clontz (1990) also demonstrated significant differences between children with CAPD and a control group for the latency and amplitude of the P300. (Levels of evidence: 2, 3).

The mismatch negativity (MMN) response is a proven research tool, with an extensive literature in peer-reviewed publications describing the MMN in normal and disordered populations of adults and children, including infants. This research indicates that the MMN reflects fundamental mechanisms of auditory processing and documents the influence of maturation and intervention on auditory processing (Näätänen, Paavilainen, Rinne, & Alho, 2007). However, given difficulties recording the response, as well as the lack of correlation between commensurate behavioral responses and the MMN, additional research is needed to determine the clinical utility of the MMN for routine clinical application in the diagnosis of (C)APD (Dalebout & Stack, 1999; Martin, Tremblay, & Korczak, 2008; see Hall, 2007, for review).

As a class of evoked potentials, studies have confirmed hemispheric asymmetry effects of varying degrees in cortical evoked potentials with speech signals in normal controls and individuals with CANS disorder (Bellis et al., 2000; Kraus et al., 1992; Tremblay et al., 2004), as well as in individuals with cochlear implants (Sharma, Dorman, & Spahr, 2002). Cortical AERs also appear to have value in documenting and monitoring the effects of intervention for (C)APD (Jirsa & Clontz, 1990; Tremblay, 2007; Tremblay & Kraus, 2002). For more details on these responses, the reader is referred to a recent review of the topic entitled "Speech Evoked Potentials: From the Laboratory to the Clinic" (Martin, et al., 2008), as well as several recent textbooks (Hall, 2007; Burkard, Don, & Eggermont, 2007).

A variety of practical issues must be considered, however, in applying cortical AERs in the clinical evaluation of (C)APD. There are no accepted protocols for AER measurement and no evidence-based recommendations for stimulus and acquisition parameters, such as the number of recording electrodes and their locations. Normative data acquired from large numbers of subjects across the lifespan are lacking for each of the major cortical AERs. Routine application of AERs as a standard clinical procedure may not always be indicated; however, there is ample evidence that for selected individuals application of these procedures can be clinically revealing or useful in terms of identifying regions of CANS involvement and/or corroborating behavioral findings. These procedures may be especially useful for intrasubject comparisons (e.g., electrode effects).

Selection of Auditory Electrophysiological Procedures

There are no widely accepted criteria as to when AERs should be included in the clinical evaluation of (C)APD. One set of recommendations (i.e., Jerger & Musiek, 2000) were met with considerable resistance (Katz et al., 2002). Clearly, the inclusion of AERs as standard protocol in the test battery for all children undergoing (C)APD evaluation would have major implications for the cost of diagnosing (C)APD and would further constrain the availability of services. In fact, AER systems with the capability for multi-channel recording (more than two electrode arrays) and the elicitation of AERs with speech signals generally are not available, even in audiology clinics within major medical centers. At this time, the instrumentation needed to perform sophisticated AER recordings is found almost exclusively in the laboratory setting. Given this limitation, coupled with the practical issues outlined immediately above, rather than recommend use of AERs in every clinical central auditory evaluation, a reasonable approach might be to define clinical situations where there are clear indications for the application of AERs. Some potential clinical indicators are when:

- behavioral assessment fails to reveal a clear pattern of deficits,
- behavioral test findings are incomplete or inconclusive or are compromised by selected listener variables (e.g., attention, motivation, cognitive status),

- the age of a young child precludes comprehensive behavioral assessment of (C)APD using behavioral measures,
- a neurologic disorder requiring medical follow-up is suspected,
- information on the site of dysfunction within the CANS is needed for individuals showing a clear pattern of (C)APD with behavioral assessment, and
- behavioral measures of (C)APD are not available in the individual's native language.

The rationale for using AERs for assessment of (C)APD is strongest for young children who cannot be assessed with a behavioral test battery. Currently, AERs are not routinely applied in the diagnosis of (C)APD; comprehensive behavioral assessment of CAPD is more commonly used. Furthermore, although electrophysiologic results can provide objective information regarding acoustic signal transmission throughout the CANS, it should be remembered that neurophysiologic responses may be entirely normal in many cases of (C)APD because neurophysiologic deficits may be diffuse and not sufficiently localized to alter electrophysiologic recordings, such as in some cases of head injury (Harris & Hall, 1990). In addition, even when neurophysiologic abnormalities are noted, these results provide little additional information (beyond that provided by the behavioral test results) regarding the functional difficulties experienced by the individual with (C)APD and, thus, may be of limited use for the development of deficit-specific and individualized intervention plans.

Interpretation of (C)APD Test Results

The longstanding principles guiding audiologic site-of-lesion diagnostic test battery construction, administration, analysis, and interpretation also are appropriately applied to guide diagnosis of (C)APD. Several audiologists with many years of experience in clinical assessment of (C)APD have independently agreed on a similar criterion for the diagnosis of (C)APD; that is, a score two standard deviations or more below the mean for at least one ear on at least two different behavioral central auditory tests (e.g., Bellis, 2003; Musiek & Chermak, 1997, 2007). This criterion, which was based largely on studies of sensitivity and specificity obtained using various cut-off values for various central auditory tests used to identify known CANS dysfunction, has also been recommended by ASHA (2005b). The criterion referenced cut-off scores are developed from normative and standardization studies obtained from normal listeners. In addition to diagnosing the presence of (C)APD, test results clarify the nature of the involved processes, including auditory strengths and weaknesses, and provide information regarding the region(s) of dysfunction within the CANS. This additional information regarding specific auditory deficits informs the development of an individualized intervention plan (as discussed in the following section).

In addition to the use of cut-off scores, ear advantage scores are powerful indicators of hemispheric dominance for language and neurologically-based language/learning disorders (e.g., Keith, 1984). For example, a child with a typically developing auditory system should exhibit similar right- and left-ear scores for tests of degraded signals and will often have greater right-ear than left-ear scores on dichotic speech tasks. This right-ear advantage diminishes and left-ear performance improves as the child matures. Findings other than these, such as an exaggerated right-ear advantage or a left-ear advantage have implications for the diagnosis of (C)APD.

At times, ostensibly conflicting test findings are obtained, such as a right-ear deficit on one task combined with a left-ear deficit on another similar task within the same individual. When such a pattern is observed, one should consider the possibility of confounding listener variables (e.g., cognitive, attention) that may be affecting test performance or multiple sites/levels of dysfunction within the CANS. Similarly, poor performance on all tests administered, regardless of processing demands, might argue for a higher-level more global attention, cognitive, or related deficit, rather than true CANS dysfunction (ASHA, 2005b). Likewise, progressively poorer scores on tests toward the end of a diagnostic session, the presence of “deficits” that resolve with reinforcement, or the observation of poor response reliability are more likely a reflection of increased fatigue and/or decreased attention or motivation rather than manifestations of true CANS dysfunction. Comparison of central auditory test battery performance patterns to those that have been well established in the auditory neuroscience literature provides useful guidance for differentiating true CANS dysfunction from other non-auditory factors that may impact central auditory test performance. For example, the finding of a left-ear deficit on dichotic speech tasks combined with a bilateral deficit on temporal patterning tasks in the linguistic labeling report condition only, coupled with normal performance on monaural low-redundancy speech tasks has been shown to be a classic indicator of corpus callosum dysfunction and is a pattern that is frequently seen in children with (C)APD (Musiek, Kibbe, & Baran, 1984; Musiek, Gollegly, & Baran, 1984).

Considerations for Additional Research

- Systematic investigation of performance on behavioral central auditory tests and electrophysiologic measures in the same subject group.
- The development of new tests for assessing each major auditory process meeting accepted psychometric criteria for test construction and sensitivity and specificity (i.e., efficiency).
- Development of non-verbal tests that can be applied universally (internationally).
- Use of brain imaging and other electrophysiologic approaches to ascertain the status of the CANS in children and adults.
- Studies of (C)APD test performance in persons with significant peripheral auditory dysfunction.
- Development and investigation of validity and efficiency of central auditory tests for children younger than age seven years.
- Large-scale studies to establish normative data for behavioral central auditory tests and AERs across the lifespan.
- New studies to update the sensitivity and specificity data for cortical AERs, particularly as they relate to the analysis and interpretation of CANS function in the diagnosis of (C)APD in children.

INTERVENTION

(C)APD manifests itself primarily in the auditory system and predominant complaints are auditory; however, due to brain organization (i.e., shared neuroanatomical substrate, parallel/distributed processing, temporal coupling across regions), (C)APD frequently co-exists with deficits in related areas (e.g., attention, language, communication, and learning) (ASHA, 2005b; Musiek et al., 2005). Intervention for (C)APD should be undertaken as soon as evidence is obtained from behavioral and/or electrophysiologic measures demonstrating CANS involvement that results in a diagnosis of (C)APD. Early identification followed by intensive intervention exploits the brain's inherent plasticity. Successful treatment outcomes are dependent on stimulation and practice that induce cortical reorganization (and possibly reorganization of the brainstem), which is reflected in behavioral change (i.e., learning) (Kolb, 1995; Merzenich & Jenkins, 1995; Russo, Nicol, Zecker, Hayes, & Kraus, 2005).

The extensive auditory system that shares neurophysiologic substrate and processing with other systems is responsible for the complex array of behavioral deficits and frequent co-morbidity; however, it also provides considerable opportunities for effective intervention by a multidisciplinary team. Understanding the linkages between brain organization and its dysfunction and resulting auditory behaviors is useful to the development of targeted, therapeutic approaches. Given the potential impact of (C)APD on listening, communication, and academic success, broad and comprehensive intervention involving a multidisciplinary team typically is required to maximize treatment effectiveness.

Intervention Components

The major components of a comprehensive, multidisciplinary intervention approach are segmented into bottom-up and top-down treatments (Chermak & Musiek, 2007). Bottom-up (i.e., stimulus driven) intervention approaches include auditory (and multimodal) training (i.e., direct auditory) skills remediation to reorganize the CANS and environmental modifications (i.e., approaches that increase clarity of signal and/or improve the listening environment, including assistive listening systems, clear speech, improved room acoustics, etc.). Top-down (i.e., strategy driven) intervention approaches include central resources training (i.e., language strategies, cognitive strategies, and metacognitive strategies), educational interventions (i.e., instructional modifications and learning strategies), and workplace, recreational and home accommodations (e.g., written directives such as memos and e-mails, posting chores on white board, etc.). These approaches build listening skills and strategies, promote efficient allocation of perceptual and higher-order resources (e.g., language, memory, attention), and provide compensatory methods to minimize functional listening deficits.

Multidisciplinary Team

Intervention planning is based on the auditory processing deficits that are documented in the diagnostic evaluation coupled with any associated functional performance deficits that may have been identified through multidisciplinary team assessment (e.g., speech-language, neuropsychology, psychoeducational, etc.). As such, intervention for individuals experiencing communicative or academic difficulty should be undertaken by a multidisciplinary team, which may include audiologists, speech-language pathologists (SLPs), educators, psychologists, parents, and others. For the small subset of children diagnosed with (C)APD who nonetheless perform at grade level due to Herculean effort and are therefore not eligible for special educational services, the audiologist may provide auditory training in the absence of a multidisciplinary effort. Similarly, adults with (C)APD who may not be able to access multidisciplinary intervention due to insurance limitations or other factors, or for whom multidisciplinary intervention is not necessary, auditory training provided by an audiologist or in some cases a speech-language pathologist should be provided. The specific composition of the team is therefore dependent on the nature of the dysfunction and the individual's complaints, as well as other external factors (e.g., insurance coverage, etc.) that may influence the composition of the team providing intervention services for the individual diagnosed with (C)APD.

Determining Goals and Documenting Improvement

The effectiveness and efficacy of (C)APD treatment outcomes should be measured in terms of improved auditory processing as documented by changes on central auditory tests and other psychoacoustic and electrophysiologic measures. Use of standardized and psychometrically sound questionnaires may offer evidence of improved function in related areas and settings (e.g., listening comprehension, academic areas, social skills, work place, etc.). However, the effectiveness and efficacy of (C)APD intervention should not be gauged by academic outcomes or improved social skills alone.

Auditory processing deficits (i.e., temporal processing, auditory pattern recognition, auditory discrimination, binaural integration, binaural separation, localization deficits) identified through diagnostic tests and procedures guide treatment goals and objectives. Clinicians should assign the highest priority for treatment to those auditory processing deficits identified through central auditory diagnostic testing considered to have the greatest functional impact (e.g., on listening, academic performance, job performance, social function). Multidisciplinary assessment for children, and where appropriate, for adults can be helpful in further elucidating functional deficits.

Intervention Principles

Treatment should be undertaken for individuals of all ages as soon as a (C)APD diagnosis is rendered. For young children suspected or "at-risk" for (C)APD but for whom a definitive diagnosis has not yet been reached, enriched auditory stimulation and auditory "games" (e.g., musical chairs, Simon Says) and/or software that exercises auditory sound recognition in noise, phoneme discrimination, etc. should be initiated and can involve families and educators.

Effective intervention should be applied consistent with neuroscience and learning principles (Chermak & Musiek, 2007; Merzenich & Jenkins, 1995). These principles indicate 1) intensive training to exploit plasticity and cortical reorganization (i.e., considerable practice and significant challenge by working near the individual's skill threshold; 2) extensive (multidisciplinary) central resources training to exploit large, shared, and overlapping auditory, cognitive, metacognitive, and language systems, and maximize generalization and effectiveness; and 3) active participation, coupled with salient reinforcement and feedback to motivate and maximize learning.

Auditory Training

An accumulating literature has demonstrated the neurophysiologic basis for auditory training, which is one of the most investigated of the treatment approaches outlined here (Palmer, Nelson, & Lindley, 1998; see Chermak, Bellis, & Musiek, 2007; Moore, 2007; Moore, Halliday, & Amitay, 2009 for reviews). The effectiveness of auditory training is maximized by:

- Varying stimuli and tasks;
- Presenting stimuli at comfortable listening levels (or slightly louder and slower; e.g., dichotic listening training, clear speech, computerized software programs that incorporate amplitude and/or transition duration changes);
- Presenting tasks systematically and graduated in difficulty to be challenging and motivating, but not so difficult as to be overwhelming (i.e., work should be focused near the individual's skill threshold);
- Targeting a moderate degree of accuracy with generous feedback and reinforcement;
- Requiring at least a moderate degree of accuracy or performance of poorer ear comparable to that of better ear before proceeding to more a demanding task;
- Providing intensive practice (i.e., frequent, perhaps daily) distributed in regard to length of training sessions, number of training sessions, time intervals between sessions, and period of time over which training is conducted (Chermak & Musiek, 2002; Musiek, Chermak, & Weihing, 2007).

The critical amount of training required for positive change varies across individuals and tasks (e.g., frequency discrimination may require more training than temporal-interval training) (Tremblay, Kraus, & McGee, 1998; Wright & Sabin, 2007). Learning is reduced if the training task is too easy or too difficult as the task demands may either under stimulate or exceed the participant's cognitive capacity, respectively, and in either case result in decreased motivation. Task-appropriate attention that challenges but does not overwhelm the participant optimizes learning (Amitay, Irwin, & Moore, 2006; Musiek et al., 2007). Nonverbal stimuli often used in auditory training drills pose a particular challenge to the clinician who must transform these rote exercises into engaging "games" when working with children.

Individualizing Intervention

Effective intervention should be evidence-based and individualized. The clinician must determine which treatments are the best for a particular individual by integrating diagnostic and assessment data and clinical expertise with the best available external clinical evidence from systematic research (Sackett & Strauss, 1998; Sackett, Strauss, Richardson, Rosenberg, & Haynes, 2000). For example, dichotic interaural intensity difference (DIID) training and multimodal exercises (e.g., linking emotion of facial expression to prosody of a message, sound-symbol association) might be appropriate treatment procedures given findings of interhemispheric transfer deficits based on pattern test and dichotic test results and multidisciplinary assessment (Bellis, 2003; Chermak & Musiek, 2007). Similarly, speech recognition in noise exercises strengthen closure skills and might be appropriate based on deficits identified on auditory performance in competition or degraded conditions. Speech recognition in noise may also strengthen interhemispheric transfer as the left hemisphere attempts to compensate for loss of phonologic information while the right hemisphere attempts to compensate for the increased attention demands resulting from noise by modulating allocation of resources between the hemispheres and filtering interhemispheric signal transmission (Banich, 1998; Boatman, Vining, Freeman, & Carson, 2003). Also illustrating the association between test results and treatment directions, the clinician might consider gap detection and cognate discrimination drills to strengthen temporal resolution deficits identified in the diagnostic test battery.

While customizing therapy for each individual is necessary, generally bottom-up and top-down treatment approaches are complementary and should both be incorporated to maximize treatment effectiveness. The clinician may determine, however, that certain strategies and exercises may be too complex and need to be adapted or eliminated as they exceed the client's cognitive, language, or intellectual capacity due to maturational factors/age or the presence of comorbid conditions (e.g., traumatic brain injury [TBI], aphasia, etc.). For example, while working memory exercises might be too demanding, reauditorization may be a particularly effective memory building approach with TBI patients (Musiek & Chermak, 2008, 2009). While bottom-up approaches may be more universally applicable across clinical populations, it still may be necessary to break the exercises down into smaller, incremental steps and reduce the intensity of training (Chermak & Musiek, 2007).

Specific treatment options (e.g., personal FM systems) may be more appropriately recommended for individuals who present deficits on monaural low-redundancy (e.g., speech recognition in noise, filtered or compressed speech) and/or dichotic speech tests. Using clear speech (i.e., focusing on a slower rate, enunciating, emphasizing key words, and pausing more often) enhances the clarity of the signal and can be effective when used alone or in combination with a personal FM system which provides acoustic enhancement. When recommending the use of a personal FM system, it is imperative that the individual using the system as well as those providing support (e.g., educator, clinician, parent) are educated about the use and care of the unit. Checklists can be utilized to help determine FM efficacy (Crandell, Smaldino, & Flexer, 2005). The individual's deficit profile also influences decisions regarding the format of therapy. For example, the clinician may determine that computerized therapy over-stimulates some TBI patients leading to a focus on therapy that is less multisensory and more face-to-face with the clinician (Musiek & Chermak, 2009). The clinician must expect that the probability of treatment success may be inversely related to the individual's degree of deficit, particularly in the neurologically involved individual.

Sources of Materials for Intervention

Materials for auditory training and central resources training are available in workbooks as well as software programs from a number of publishers. Computer-assisted programs present many advantages, including an engaging format, multisensory stimulation, generous feedback and reinforcement, and perhaps most importantly, the opportunity for intensive, adaptive, and therefore efficient training (Chermak et al., 2007). Central auditory tests, tests and materials used for assessment of individuals with cochlear implants, and tests and materials used to develop English in English language learners also may be useful.

Alternative Sound-Based Programs

Commercially available alternative sound-based treatment programs that purport to address central auditory processing problems (as well as a range of other disorders including autism) are frequently promoted by practitioners from related professions (e.g., occupational therapy). These treatment programs (e.g., Berard Auditory Integration, Tomatis Approach, Listening Program) have not been supported by the major professional associations representing audiology and pediatrics due to the lack of evidence demonstrating efficacy, questionable scientific foundations, poor research designs, and potential to cause harm due to lack of acoustic rigor and controls (e.g., excessive noise levels) (AAA, 1993; AAP, 1998; ASHA, 1994, 2004a; EAA, 1997; Corbett, Shickman, & Ferrer, 2007; Gravel, 1994; Hall & Case-Smith, 2007; Sinha, Silove, Wheeler, & Williams, 2006). Indeed, only a few observational studies without controls (level 4) and so-called “expert” opinion (level 5) support these alternative approaches. No definitive evidence supports the benefits of these alternative approaches in improving sensory and behavioral profiles. When improvements have been noted, these may have been due to generalized benefits (e.g., improved attention skills), irrespective of features supposedly addressed by the specific treatment regimen. Consequently, similar gains may be achieved from other approaches demonstrated to be safe and less costly. Before electing to use any treatment program, clinicians are advised to (1) analyze task demands and exercises to determine whether they target the identified auditory deficits, (2) ascertain that the treatment relies on the individual’s active (versus passive) participation, motivates the individual, and provides salient reinforcement, and (3) determine that the treatment purports to effect change through anatomic and/or physiologic mechanisms consistent with the science underlying central auditory processing while posing no risk of harm to the individual (Bellis, 2008).

Efficacy of Intervention Approaches

Copious levels 2 and 3 evidence supports the benefits of enhanced classroom acoustics (e.g., reduced noise levels, improved signal-to-noise ratio, and appropriate reverberation time) for speech recognition and educational and social development for children with disabilities, non-native English speakers, and normally developing children (see ASHA, 2005b, for review). Evidence supporting the relative effectiveness and efficacy of auditory (and auditory-language) training techniques is accumulating (see Thibodeau, 2007, for review). Several studies have provided level 2 and 4 evidence of the effectiveness of auditory training techniques, including the DIID or a sound field modification of the DIID paradigm (Moncrieff & Wertz, 2008; Musiek, Baran, & Shinn, 2004; Musiek & Schochat, 1998; Putter-Katz, Adi-Bensaid, Feldman, & Hildesheimer, 2008). Other studies have provided level 1 and level 2 evidence of the efficacy of some computerized auditory-language packages for children with language impairments, learning problems, reading impairment, and dyslexia, including children with presumed auditory-based impairments (e.g., Agnew, Dorn, & Eden, 2004; Cohen et al., 2005; Gillam, Crofford, Gale, & Hoffman, 2001; Gillam, Loeb, Hoffman, Bohman, Champlin, Thibodeau, Widen, Brandel, & Friel-Patti, 2008; Hayes, Warrier, Nicol, Zecker, & Kraus, 2003; Kujala, Karma, Ceponiene, Belitz, Turkkila, Tervaniemi, & Näätänen, 2001; Moore, Rosenberg, & Coleman, 2005; Russo et al., 2005; Tallal et al., 1996; Temple et al., 2003; Warrier, Johnson, Hayes, Nicol, & Kraus, 2004). The few studies that have involved software comparisons have reported little benefit for one computerized program over another (Cohen et al., 2005; Gillam et al., 2001; Gillam et al., 2008) and have concluded that modified speech is not a necessary component of effective interventions to improve language/auditory processing outcomes (Gillam et al., 2008).

Evidence supporting the benefit of coupling computer-mediated activities with experiential, functional activities to build skills and strategies that generalize is restricted to levels 4 and 5. Level 2 evidence has documented the effectiveness of clear speech in improving speech recognition in noise in children with auditory-based learning problems (Bradlow, Kraus, & Hayes, 2003; Cunningham, Nicol, Zecker, Bradlow, & Kraus, 2001), while evidence supporting the utility of central resources training (i.e., language strategies, cognitive strategies, and metacognitive strategies) has been obtained for the most part with individuals not specifically diagnosed with (C)APD (see Chermak & Musiek, 1997 for review). Studies conducted on children with listening comprehension difficulties, learning disabilities and/or (C)APD diagnoses, as well as adults with hearing impairment provide some level 2, and primarily levels 3, 4, and 5 evidence supporting the effectiveness of central resources training in a variety of learning situations (e.g., Aarnoutse, Van Den Bos, Kees, & Brand-Gruwel, 1998; Brand-Gruwel, Aarnoutse, & Van Den Bos, 1998; Jirsa, 1992; Musiek, 1999; Musiek et al., 2004; Pressley, Johnson, & Symons, 1987; Putter-Katz et al., 2008; Sweetow & Sabes, 2006). Despite considerable level 3 and level 4 evidence documenting the benefits of sound field FM amplification for listening and learning in children with normal hearing, developmental disabilities, and mild hearing loss are available (e.g., Eriks-Brophy & Ayukawa, 2000; Flexer, Millin, & Brown, 1990; Neuss, Blair, & Viehweg, 1991; Rosenberg et al., 1999); see Rosenberg, 2005, for a review), the Acoustical Society of America has recommended that sound amplification not be routinely employed in typical small mainstream classrooms, noting that sound field amplification increases rather than reduces overall classroom sound levels and may be counterproductive in reverberant rooms (ASA, 2003).

Accumulating level 2 evidence supports the multiple benefits of personal FM systems and classroom amplification for speech perception in quiet and in noise, academic performance, and psychosocial function for individuals with (C)APD and auditory-based learning problems (e.g., Anderson, Goldstein, Colodzin, & Iglehart, 2005; Blake, Field, Foster, Platt, & Wertz, 1991; Johnston, John, Kreisman, Hall, & Crandell, 2009). Single-subject studies (level 3 evidence) (e.g., Anderson & Goldstein, 2004) support the effectiveness of personal FM desktop, and sound field systems for speech recognition in noise and reverberation, and case studies (level 4 evidence) (e.g., Stach et al., 1987) support the effectiveness of personal FM systems for improved attending behaviors, speech recognition in competition, and learning.

Additional research is needed to demonstrate the effectiveness and efficacy of (C)APD treatment approaches, especially the highest level of evidence (e.g., double-blind, prospective, randomized clinical trials, time-series, and meta-analysis) using both auditory and behavioral outcome measures and electrophysiologic outcome measures with individuals specifically diagnosed with (C)APD. However, sufficient evidence is available at this time to guide intervention for (C)APD using the information gained from the audiologic diagnosis and multidisciplinary assessment across functional domains.

Considerations for Additional Research

- Additional research to demonstrate the effectiveness and efficacy of current (C)APD intervention approaches with individuals specifically diagnosed with (C)APD.
- Additional research comparing currently available software programs purportedly beneficial for treatment of (C)APD using populations specifically diagnosed with (C)APD.
- Development of additional interventions for use in clinics, schools and home settings.

PROFESSIONAL ISSUES, TRAINING, AND EDUCATION

Status of (C)APD Within Audiology

(C)APD is a disorder that has attracted considerable attention over the last 30 years, during which time major conferences have been held and professional committees and task forces have issued reports focusing on the nature of central auditory processing and its disorders, its diagnosis, and its remediation. Since the early 1990s, four major reports and position papers have been published (ASHA, 1992, 1996, 2005b; Jerger & Musiek, 2000). These publications provided important information on the definition and nature of (C)APD, an appropriate diagnostic test battery approach, and approaches to intervention. The publication of the current guidelines provides additional confirmation of the importance of this topic and the need for updated clinical guidance.

Another indicator of the continuing growth in research and clinical interest in (C)APD is the increasing number of publications that have appeared in peer-reviewed journals (e.g., American Journal of Audiology, Ear and Hearing, International Journal of Audiology, Journal of the American Academy of Audiology, among others). Similarly, there has been a tremendous increase in the number of presentations on this topic at local, state, national, and international scientific and professional meetings, as well as workshops and in-service meetings in schools, medical centers, and related professional organizations. Another expression of interest is the number of state departments of education that have published documents that elucidate (C)APD for educators within their states. These documents are useful resources for many professionals and many can be accessed via the Internet. In fact, there is a plethora of information available on the Internet, some of questionable accuracy and value, but clearly reflecting broad-based interest in this topic.

Education, Training, and Practice in (C)APD

(C)APD is a specialty area within the field of audiology. As such, not all audiologists are involved in its diagnosis or intervention. Two surveys conducted over the last ten years (Chermak, Silva, Nye, Hasbrouck, & Musiek, 2007; Chermak, Traynham, Seikel, & Musiek, 1998) found that many audiologists are not engaged in this area of practice. A comparison of the data presented in these two surveys revealed an increased percentage of audiologists who reported having completed at least one course devoted to central auditory processing in their graduate programs over this ten year period (20% in 1998 versus 69% in 2007). However, in the realm of clinical preparation, the results revealed little practicum experience with this disorder in spite of the improved academic preparation, with an average of only 12 hours of clinical experience with (C)APD being reported in the 2007 survey. Certainly, this is not a sufficient amount of time to master the underlying concepts and practices needed to accurately diagnose and treat (C)APD, which is the likely reason that only 27% of the clinicians who responded to the 2007 survey indicated that they routinely assessed central auditory processing as part of their clinical practices. Corroborating data were reported by Sykes, Tucker, and Herr (1997) who noted that audiology faculty listed central auditory diagnosis and intervention as the least important among five audiology practice areas (i.e., hearing aids, tinnitus, cochlear implants, and dizziness were all ranked higher in importance). It is likely that these attitudes have adversely impacted students' opportunities for clinical experiences in (C)APD. With the expanded Au.D. curriculum now the mainstay of audiology education, one would expect an increase in professional preparation in this area.

As revealed by the Chermak et al. (2007) survey, additional course work in this area is being offered in many university Au.D. programs. However, given the complexity of this disorder and its roots in auditory neuroscience, it is likely that additional courses pertaining to the scientific and the clinical aspects of this disorder, including neuroscience and cognitive psychology, as well as central auditory testing and intervention, will be needed.

For audiologists already in the field, there is significant need for additional continuing education opportunities. As noted above, many practicing audiologists did not receive sufficient education and training in (C)APD in their graduate programs. Although most continuing education in this area continues to be available primarily through publications and presentations at state and national conventions, as well as through a few regional and national conferences dedicated to the topic of (C)APD that are offered sporadically, a recent on-line conference (September 2007) sponsored by ASHA may presage a change in continuing education in an electronic age. However, distance learning programs provided by university graduate programs remain sparse and may reflect the relatively low status of courses and practicum opportunities in this topic area that are available to current Au.D. students. In addition, individuals within departments and university programs who may be interested in convening a conference on this topic are met with competition for learning opportunities from many sources, high production costs, and endless paperwork to acquire necessary approvals and process required CEU applications. All of these obstacles act as disincentives to making (C)APD conferences available on a frequent basis. To resolve these problems there appears to be a need for more regional conferences provided by collective state organizational efforts and national organizations. Additional on-line conferences following the ASHA web-based conference also are desirable as they minimize travel and allow individuals to participate on their own time. Post-graduate clinical training opportunities (comparable to a post-doctoral research position) for seasoned audiologists would provide audiologists with additional opportunities for continued clinical training. One possible solution to the limitations of graduate education and post-graduate training in (C)APD is to convene a national conference that develops a model university curriculum for the topic of (C)APD, clarifies the practicum experiences required for competence in diagnosis and intervention, and provides recommendations for ongoing post-graduate (continuing) education.

Collaboration with Other Professionals and Families

(C)APD assessment and intervention requires collaboration with related professionals. (see ASHA, 2005b, for level 5 evidence). Physicians are an important referral source, as they are often the first professional to whom parents turn when their children experience "listening" and/or academic difficulties, and to whom adults turn when experiencing "hearing" and communication problems. Audiologists most frequently partner with speech-language pathologists in the screening, assessment, and intervention for (C)APD since speech-language pathologists are the professionals whose scope of practice includes assessment of the cognitive-communicative and language abilities associated with (C)APD (ASHA, 2004b, 2007). Speech-language pathologists frequently refer individuals to audiologists for central auditory testing on the basis of observed behavioral characteristics and/or results of a screening questionnaire or screening test (see Patient History and Selection Criteria section). Subsequent to a central auditory evaluation, a speech-language pathologist can explore the possible impact of auditory processing-related deficits on specific aspects of language processing. Conversely, an initial speech-language evaluation may suggest underlying central auditory processing deficits, with subsequent referral for a central auditory processing evaluation. Speech-language pathologists also are best prepared to provide a number of the interventions elaborated in the preceding section of these guidelines (e.g., central resources training). In individuals with processing difficulties due to frank neurological lesions, audiologists and neurologists collaboratively play significant roles in identifying the likely site or sites of CANS dysfunction, as well as their impact on the processing of acoustic and spoken language stimuli.

Other professional groups, including psychologists and educators, are often engaged in the intervention plan, especially for children. School psychologists evaluate the child's cognitive abilities in a number of domains including verbal and non-verbal abilities, cognitive capacity, and attentional issues. This information provides the audiologist with information regarding the child's ability to participate in central auditory testing, including insights as to potential confounds. Teachers serve an important role in identifying children "at risk" for (C)APD, and along with physicians serve as a major source of referrals to the audiologist. In addition to referring "at-risk" children for evaluation, teachers can inform the multidisciplinary assessment in reporting a child's processing strengths and weaknesses, implementing programmatic accommodations recommended by the audiologist, including those included on either the Individualized Educational Plan (IEP) or 504 Plan, and assisting in monitoring progress through administration of pre- and post-intervention questionnaires.

Occupational therapists may also serve a supporting role in assessment and intervention for (C)APD. In instances where a sensory integration disorder (also known as regulatory-sensory processing disorder) or a motor-sequencing deficit has been identified, the audiologist may confer with the occupational therapist to determine potential interactions between these purportedly pansensory deficits and a (C)APD.

Unfortunately, it appears that little information about (C)APD appears in other professions' journals, text books and conferences. This suggests an opportunity for audiologists to reach out and increase the visibility and understanding of this disorder and opportunities for involvement among other professionals.

Parents' understanding of (C)APD is difficult to judge, although most parents referred to clinics for central auditory testing of their children seem to have heard of this disorder before arriving for the evaluation. There appears to be a dramatic increase in requests for central auditory evaluation and intervention services in the schools. As Bellis stated, "Unfortunately, this increase in awareness has resulted in a plethora of misconceptions and misinformation, as well as confusion regarding just what is (and isn't) an APD [(C)APD], how APD [(C)APD], is diagnosed, and methods of managing and treating the disorder." (Bellis, n.d.). In increasing numbers, parents are seeking the advice of audiologists to determine whether their children have (C)APD, frequently in an attempt to explain why their children's auditory behavior and learning seem to be disordered. Some parents seek a diagnosis of (C)APD as a substitute for another diagnosis that seems less "acceptable" to them, or to explain academic performance that may be attributable to other causes, or when other professions have failed to identify the underlying source of a child's difficulties.

Among adults, understanding of (C)APD is often the result of collaborative efforts of both audiologists and physicians in addressing processing-related deficits subsequent to medical conditions and head-related traumas. Because the changes caused by the (C)APD typically are quite apparent, it is relatively easy for these adults and families, friends, and associates to acknowledge and comprehend their condition. Another group of adults that increasingly seek (C)APD services is comprised of individuals who have struggled in school but did not receive any diagnostic or intervention services. Due to exposure to this topic (either because their children are receiving (C)APD services, or through the media), they have decided to seek (C)APD evaluation and intervention.

Increasing Awareness of (C)APD Among Other Professionals

If audiologists are to successfully address the needs of children and adults with (C)APD, it is imperative that other professionals who supply background information and refer individuals to the audiologist and/or participate in the interventions for (C)APD are aware of the requirements for diagnosis of (C)APD and the range of available clinical and related services to maximize an individual's success. One of the most fundamental means for audiologists to educate other professionals is through well written reports that clearly describe (1) the various test procedures administered and test results obtained, (2) the overall implications of the test findings, and (3) the recommendations for intervention to remediate and/or compensate for the deficits identified. While raw scores may not be essential in such reports, the audiologist should interpret the scores relative to age-appropriate norms and explain the potential social, educational, and medical implications and recommendations for improving the individual's auditory and communicative functions and learning. Audiologists may also increase awareness and understanding of (C)APD by providing in-services and workshops at meetings of related professionals. These settings also provide an opportunity for multidisciplinary discussion and problem solving. When working with teachers who may not have been exposed to (C)APD in their professional preparation programs it is incumbent upon the audiologist to enhance the teacher's knowledge base regarding the nature of this disorder and the various intervention strategies that can be utilized to assist the child within the academic setting. This can be accomplished through one-on-one discussions with the student's teacher(s), school presentations, and provision of written materials. Similarly, audiologists connected with teaching hospitals can provide lectures to medical students and residents in a wide range of specialties including pediatrics, otolaryngology, family practice, internal medicine, neurology, and geriatrics, as well as participate in grand rounds with practicing physicians.

Eligibility for Special Services within the Schools

There are two mechanisms by which a student diagnosed with a disability can receive services through a school. One means is through an IEP (required by the Individuals with Disabilities Education Act (IDEA), 20 U.S.C. Section 1400 et seq.) which funds special education and related services if the student is determined to have one of 13 specified disabilities and that disability adversely affects the student's educational performance. The second mechanism is through a 504 Plan (Section 504 of the Federal Rehabilitation Act of 1974) whereby all school-aged children identified as disabled (i.e., having a physical or mental impairment substantially limiting a major life activity) are entitled to receive an education comparable to that provided to students without disabilities. A student is eligible for a 504 Plan as long as s/he meets the definition of a qualified person with a disability, even if the disability does not adversely affect educational performance. Unlike IDEA, 504 Plans do not provide funding to achieve a comparable education. The goal of comparable education is to be attained through the implementation of reasonable accommodations.

Audiologists working with children diagnosed with (C)APD play an important role in advocating on the student's behalf at school team/school district meetings. Because intervention initiatives entail the development of an IEP or 504 Plan, it is imperative that the audiologist become knowledgeable about the various legal provisions entailed by each law. This knowledge will allow the audiologist to assist school personnel in determining: (1) the impact of the (C)APD relative to the specific disability guidelines entailed within each law; (2) which, if either law, more appropriately addresses the student's specific difficulties; and (3) which services and accommodations should be included in the IEP. If the overall disability is determined by the Committee on Special Education (CSE) to impact education (i.e., result in the implementation of an IEP), then the central auditory test results are incorporated in the development of specific content within the IEP (e.g., need for an FM system, further testing or therapy, programmatic accommodations, and/or the implementation of various interventions). If the student's disability is judged not to significantly impact academic performance, but does impact the student's ability to access and benefit from his or her academic placement, then the central auditory test results still may be used to provide assistance in developing a 504 Plan to address issues such as testing and programmatic accommodations, implementation of compensatory strategies, and possibly in the provision of related services though funding sources other than federal monies. It should be noted that an individual with (C)APD may be classified by the CSE only if other "covered" comorbid condition(s) are identified (e.g., speech-language impairment, learning disability, or "other health" impairment).

Reimbursement for Central Auditory Testing

The following discussion pertains to behavioral central auditory testing. Current procedure terminology (CPT) codes as listed in the January 2009 CPT Manual supersede any previous billing mechanisms for central auditory procedures and reflect face-to-face professional time and services provided in a (C)APD evaluation. The first hour of administering, interpreting, and/or providing test results falls under CPT code 92620, with each additional 15 minute increment billed under CPT code 92621. A maximum of eight additional units is allowed by many third party payers. The codes for auditory processing are distinct from the peripheral hearing assessment as well as from the administration of electrophysiologic procedures (these procedures are billed separately using the appropriate CPT codes). Note that billing for counseling (i.e., review of test findings) is allowed only if it occurs on the same day as testing. Billing for report writing should be limited to a maximum of 15-30 minutes as a practical matter for most third party payers.

Audiologists have raised a number of concerns regarding reimbursement, including the adequacy of reimbursement rates, variation in commercial insurance coverage across states, and denial of claims. Medicare reimburses diagnostic procedures conducted only for medically-necessary reasons. Commercial payers (e.g., Aetna, Humana, Blue Cross Blue Shield and others) tend to follow Medicare guidelines, but also have the latitude to deviate from Medicare. As such, commercial payers are not obligated to reimburse for auditory processing testing. Because there is sufficient variability in insurance/HMO coverage for auditory processing evaluations, testing should not be completed without obtaining prior authorization or pre-certification. When an insurer denies claims for payment, audiologists should provide information to the insurer documenting the clinical efficacy of central auditory testing and how the results of an accurate (C)APD diagnosis will decrease insurance costs in the long run (e.g., as in individuals incorrectly identified with ADHD).

Also of concern is the variation across states in coverage for central auditory testing provided by Medicaid and various Medicaid option plans, as well as state-offered insurance plans for children. Audiologists must determine the specific coverage limitations for their states.

Adequate reimbursement is always a significant concern given the time commitments of an auditory processing evaluation. Medicare's base rate of reimbursement for 92620 for a non-facility entity (i.e., excludes hospitals, skilled nursing facilities, rehabilitation agencies) is $85.98. The add-on 15 minute code (92621) has a base rate of reimbursement of $19.84. The actual Medicare reimbursement varies slightly across geographic regions and is adjusted using Geographic Practice Cost Indices (GPCI) multipliers. For example, the reimbursement for 92620 for Albany, NY is $82.74, whereas the reimbursement for the same procedure in Detroit, MI is $90.46. The reimbursement amount varies according to the cost of providing care in various locales, but usually does not vary more than a few dollars.

For illustrative purposes, let us say that a private practice-based audiologist provides the following:

- a comprehensive central auditory evaluation (e.g., history plus 4-5 tests) entailing 1 hour of testing,
- 30 minutes devoted to report generation, and
- 30 minutes to review the results with parents or adult patient.

Using the base reimbursement values, the Medicare reimbursement for this evaluation would be $165.34 (CPT code-92620 for the first hour of testing plus 4 units of CPT code 92621). If the audiologist is affiliated with a facility (i.e., hospital, skilled nursing facility, rehabilitation agency), Medicare reimbursement would fall under the Hospital Outpatient Prospective Payment System (HOPPS), which is much different than the fee-for-service arrangement of the Medicare Physician Fee Schedule. Under HOPPS, each procedure is classified into a payment category with no allowance for timed codes or add-on codes. CPT 92620 reimbursement under HOPPS is $84.44 for the complete evaluation regardless of length of time. No additional reimbursement for procedural code 92621 is allowed to entities classified as a facility).

Most commercial payers have adopted aspects of Medicare's Resource Based Relative Value System (RBVS), but not the dollar values. As a result, some payers are more generous than Medicare, while others are much less so. Each audiologist must establish a reasonable and justifiable charge for this service that will be unique to his/her practice setting based on the cost of service delivery. Contributing factors for the cost calculations include equipment, test materials, disposable supplies, professional continuing education and training, and indirect costs (e.g., rent, utilities, support personnel salary/benefits, audiologist salary/benefits, licenses, insurance, etc). In addition, for many individuals whose insurance does not cover central auditory testing, audiologists must demonstrate the true value of this testing in a way that allows patients and families to perceive value and benefit for each dollar they spend on this service.

Professional Ethics

As is true for all professional practice areas, audiologists must abide by the highest professional standards of integrity and ethical principles for the proper delivery of clinical services. Audiologists must have the knowledge and skills needed to competently diagnose and provide intervention for (C)APD. If such preparation was not fully obtained in the university education program, such preparation must be obtained through rigorous continuing education prior to participating in this clinical practice area. The professional code of ethics also obligates audiologists to maintain the highest level of professional competence, which inevitably requires ongoing post-graduate, continuing education.

Audiologists must collaborate with other professionals in referring for testing that falls outside their own scope of practice (e.g., to assess possible comorbid conditions, including ADHD, language impairment, etc.) and to provide the range of appropriate interventions necessary to improve the listening, communication and learning problems frequently associated with (C)APD. In addition, audiologists must not engage in clinical practices that lack substantive scientific basis and are not in the best interests of those served. Many of the so-called “sound-based training approaches,” discussed earlier in the report, lack published, peer-reviewed evidence-based research to support their use. Incorporating these alternative approaches in one’s practice would not serve the individual’s best interests and would therefore violate the Code of Ethics of the American Academy of Audiology (AAA, 2009), and the Code of Ethics of the American Speech-Language-Hearing Association (ASHA, (2010). Audiologists should be prepared to respond to parents or other professionals seeking an opinion or referral for these alternative approaches by conveying the lack of scientific foundation for these approaches and their claims and by conveying the likelihood that the cost for these approaches will far exceed their benefits, if any, and may in fact harm the individual. Discussion should then be directed to ascertaining that the individual has been appropriately diagnosed and fully assessed, and only at that point should the audiologist offer evidence-based recommendations for intervention.

Considerations for Additional Research

- Outcome studies to document the efficacy and effectiveness of school-based services to children diagnosed with (C)APD.
- Studies providing documentation supporting increased third party reimbursement for (C)APD diagnostic and treatment services.
- Studies to develop improved approaches to professional education, collaboration and dissemination of information pertaining to professional issues.

CONCLUDING COMMENTS

These clinical practice guidelines provide evidence-based recommendations for the diagnosis, treatment, and management of children and adults with (central) auditory processing disorder ([C])APD). The guidelines emphasize: 1) the variety of etiologies involving deficits in the function of the central auditory nervous system; 2) the diversity of populations, including children, adults, and the elderly presenting with (C)APD; 3) the use of efficient (i.e., sensitive and specific) behavioral tests and electrophysiologic procedures to accurately diagnose (C)APD; 4) the need to consider possible comorbid disorders which may necessitate modifications to the diagnostic test battery and interpretation of test results; 5) the pivotal role of neuroplasticity in reducing central auditory processing deficits and effecting behavioral change through intensive auditory training and the learning of compensatory strategies; and 6) the value of a multidisciplinary team approach in the broad assessment of functional deficits associated with (C)APD and in planning intervention for the individual diagnosed with (C)APD. The guidelines provide direction to clinicians involved in this practice area and serve as resource to the AAA and its membership for communication with the public.

REFERENCES

Aarnoutse, C.A.J., Van Den Bos, K.P., Kees, P., & Brand-Gruwel, S. (1998). Effects of listening comprehension training on listening and reading. Journal of Special Education, 32(2), 115-126.

Acoustical Society of America (2003). Position on the use of sound amplification in the classroom [Position Statement]. Retrieved from http://asa.aip.org/amplification.pdf

Agnew, J.A., Dorn, C., & Eden, G.F. (2004). Effect of intensive training on auditory processing and reading skills. Brain and Language, 88(1), 21-25.

Aharonson, V., Furst, M., Levine, R.A., Chaigrecht, M., & Korczyn, A.D. (1998). Lateralization

and binaural discrimination of patients with pontine lesions. Journal of the Acoustical Society of America, 103(5 Pt. 1), 2624-2633.

American Academy of Audiology (1993). Auditory integration training [Position Statement]. Audiology Today, 5(4), 21.

American Academy of Audiology (2004). Scope of practice [Scope of Practice]. Retrieved from http://www.audiology.org/resources/documentlibrary/Pages/ScopeofPractice.aspx

American Academy of Audiology (2009). Code of ethics [Ethics]. Retrieved from http://www.audiology.org/resources/documentlibrary/Pages/codeofethics.aspx

American Academy of Pediatrics (1998). Auditory integration training and facilitated communication for autism [Policy Statement]. Pediatrics, 102(2), 431-433.

American Speech-Language-Hearing Association (1992). Issues in central auditory processing disorders: A report form the ASHA ad hoc committee on central auditory processing. Rockville, MD. Author.

American Speech-Language-Hearing Association (1994). Auditory integration training. ASHA, 36(10), 55-58.

American Speech-Language-Hearing Association (1996). Central auditory processing: Current status of research and implications for clinical practice [Technical Report]. American Journal of Audiology, 5(2), 41-54.

American Speech-Language-Hearing Association (2004a). Auditory integration training [Technical Report]. Retrieved from http://www.asha.org/docs/html/TR2004-00260.html

American Speech-Language Hearing Association (2004b). Preferred practice patterns for the profession of speech-language pathology [Preferred Practice Patterns]. Retrieved from http://www.asha.org/members/deskref-journals/deskref/default

American Speech-Language-Hearing Association (2004c). *Scope of practice in audiology* [Scope of Practice]. Retrieved from http://www.asha.org/docs/html/SP2004-00192.html

American Speech-Language-Hearing Association (2005a). *Acoustics in educational settings: Technical Report* [Technical Report]. Retrieved from http://www.asha.org/docs/html/PS2005-00028.html

American Speech-Language-Hearing Association (2005b). (Central) auditory processing disorders [Technical Report]. Retrieved from http://www.asha.org/docs/html/TR2005-00043.html

American Speech-Language-Hearing Association (2005c). *(Central) auditory processing disorders - The role of the audiologist* [Position Statement]. Retrieved from http://www.asha.org/docs/html/PS2005-00114.html

American Speech-Language-Hearing Association (2006). *Preferred practice patterns for the profession of audiology* [Preferred Practice Patterns]. Retrieved from http://www.asha.org/docs/html/PP2006-00274.html

American Speech-Language-Hearing Association (2007). *Scope of practice in speech-language pathology* [Scope of Practice]. Retrieved from http://www.asha.org/docs/html/SP2007-00283.html

American Speech-Language-Hearing Association (2010). Code of ethics [Ethics]. Retrieved from http://www.asha.org/docs/html/ET2010-00309.html

Amitay, S., Irwin, A., & Moore, D.R. (2006). Discrimination learning induced by training with identical stimuli. Nature Neuroscience, 9(11), 1146-1148.

Anderson, K.L., & Goldstein, H. (2004). Speech perception benefits of FM and infrared devices to children with hearing aids in a typical classroom. Language, Speech, and Hearing Services in Schools, 35, 169-184.

Anderson, K., Goldstein, H., Colodzin, L., & Iglehart, F. (2005). Benefit of S/N enhancing devices to speech perception of children listening in a typical classroom with hearing aids or cochlear implant. Journal of Educational Audiology, 12, 14-28.

Anderson, K.L., & Matkin, N. (1996). Screening Instrument for Targeting Educational Risk in Pre-school Children (Age 3 - Kindergarten). Tampa, FL: Educational Audiology Association.

Anderson, K., & Smaldino, J. (1998). Listening Inventories for Education: A classroom measurement tool. Hearing Journal, 52, 74-76.

Anderson, K.L., & Smaldino, J.J. (2000). Children's Home Inventory for Listening Difficulties (CHILD). Educational Audiology Review, 17(3 Suppl.).

Bamiou, D.E., Musiek, F.E., & Luxon, L.M. (2001). Aetiology and clinical presentations of auditory processing disorders - a review. Archives of Disease in Childhood, 85(5), 361-365.

Bamiou, D.E., Musiek, F.E., Stow, I., Stevens, J., Cipolotti, L., Brown, M.M., & Luxon, L.M. (2006). Auditory temporal processing deficits in patients with insular stroke. Neurology, 67(4), 614-619.

Banai, K., Nicol, T., Zecker, S.G., & Kraus, N. (2005). Brainstem timing: Implications for cortical processing and literacy. Journal of Neuroscience, 25(43), 9850-9857.

Banich, M.T. (1998). The missing link: The role of interhemispheric interaction in attentional processing. Brain and Cognition, 36(2), 128-157.

Baran, J.A. (2007). Test battery considerations. In F.E. Musiek & G.D. Chermak (Eds.), Handbook of (central) auditory processing disorder: Auditory neuroscience and diagnosis (Vol. 1, pp. 163-192). San Diego, CA: Plural Publishing.

Baran, J.A., & Musiek, F.E. (1999). Behavioral assessment of the central auditory nervous system. In F.E. Musiek & W.F. Rintelmann (Eds.), Contemporary perspectives in hearing assessment (pp. 375-413). Boston, MA: Allyn & Bacon.

Baran, J.A., Musiek, F.E., & Reeves, A.G. (1986). Central auditory function following anterior sectioning of the corpus callosum. Ear and Hearing, 7(6), 359-362.

Barlow, D.H., & Hersen, M. (1984). Single case experimental designs: Strategies for studying behavior change. New York, NY: Pergamon Press.

Bayazit, O., Öniz, A., Hahn, C., Güntürkün, O., & Ozgören, M. (2009). Dichotic listening revisited: Trial-by-trial ERP analyses reveal intra- and interhemispheric differences. Neuropsychologica, 47(2), 536-545.

Beasley, D.S., Schwimmer, S., & Rintelmann, W.F. (1972). Intelligibility of time-compressed CNC monosyllables. Journal of Speech and Hearing Research, 15(2), 340-350.

Bellis, T.J. (2003). Assessment and management of central auditory processing disorders in the educational setting: From science to practice (2nd ed.). Clifton Park, NY: Thomson Learning, Inc.

Bellis, T.J. (2007). Differential diagnosis of (central) auditory processing disorder in older listeners. In F.E. Musiek & G.D. Chermak (Eds.), Handbook of (central) auditory processing disorder: Auditory neuroscience and diagnosis (Vol. 1, pp. 319-346). San Diego, CA: Plural Publishing.

Bellis, T.J. (2008). Treatment of (central) auditory processing disorders. In M. Valente, H. Hosford-Dunn, & R.J. Roeser (Eds.). Audiology: Treatment (2nd ed., pp. 271-292). New York, NY: Thieme Medical Publishers.

Bellis, T.J. (n.d.). Understanding auditory processing disorders in children. Retrieved from http://www.asha.org/public/hearing/disorders/understand-apd-child.htm.

Bellis, T.J., Nicol, T., & Kraus, N. (2000). Aging affects hemispheric asymmetry in the neural representation of speech sounds. Journal of Neuroscience, 20(2), 791-797.

Bellis, T.J., & Wilber, L.A. (2001). Effects of aging and gender on interhemispheric function. Journal of Speech, Language, and Hearing Research, 44(2), 246-263.

Bergemalm, P.O., & Lyxell, B. (2005). Appearances are deceptive? Long-term cognitive and central auditory sequelae from closed head injury. International Journal of Audiology, 44(1), 39-49.

Blaettner, U., Scherg, M., & von Cramon, D. (1989). Diagnosis of unilateral telencephalic hearing disorders: Evaluation of a simple psychoacoustic pattern discrimination test. Brain, 112(1), 177-195.

Blake, R., Field, B., Foster, C., Platt, F., & Wertz, P. (1991). Effect of FM auditory trainers on attending behaviors of learning-disabled children. *Language, Speech, and Hearing Services in Schools, 22*, 111–114.

Boatman, D., Vining, E.P., Freeman, J., & Carson, B. (2003). Auditory processing studied prospectively in two hemide-corticectomy patients. Journal of Child Neurology, 18(3), 228-232.

Bocca, E., *Calearo*, C., & *Cassinari*, V. (*1954*). A new method for testing hearing in temporal lobe tumors: Preliminary report. Acta Otolaryngology, 44(3), 219-221.

Bornstein, S.P., Wilson, R.H., & Cambron, N.K. (1994). Low- and high-pass filtered

Northwestern University Auditory Test No. 6 for monaural and binaural

evaluation. Journal of the American Academy of Audiology, 5(4), 259-264.

Boscariol, M., Garcia, V.L., Guimarães, C.A., Hage, S.R., Montenegro, M.A., Cendes, F., &

Guerreiro, M.M. (2009). Auditory processing disorders in twins with perisylvian

polymicrogyria. Arquivos de Neuro-Psiquiatria, 67(2-B), 499-501.

Boscariol, M., Garcia, V.L., Guimarães C.A., Montenegro, M.A., Hage, S.R., Cendes, F., &

Guerreiro, M.M. (2010). Auditory processing disorder in perisylvian syndrome. Brain and Development, 32(4), 299-304.

Bradlow, A.R., Kraus, N., & Hayes, E. (2003). Speaking clearly for children with learning disabilities: Sentence perception in noise. Journal of Speech, Language, and Hearing Research, 46(1), 80-97.

Brand-Gruwel, S., Aarnoutse, C.A.J., & Van Den Bos, K.P. (1998). Improving text comprehension strategies in reading and listening settings. Learning and Instruction, 8(1), 63-81.

British Society of Audiology (2007). Auditory Processing Disorder Steering Committee Interim Position Statement on APD [Position Statement]. Retrieved from http://www.thebsa.org.uk/apd/BSA_APD_Position_statement_Final_Draft_Feb_2007.pdf

Broadbent, D.E. (1954). The role of auditory localization in attention and memory span. Journal of Experimental Psychology, 47(3), 191-196.

Burkard, R.F., Don, M., & Eggermont, J.J. (Eds.), Auditory evoked potentials: Basic principles and clinical application. Baltimore, MD: Lippincott Williams & Wilkins.

Cacace, A.T., & McFarland, D.J. (2005). The importance of modality specificity in diagnosing

central auditory processing disorder. American Journal of Audiology, 14(2), 112-123.

Cameron, S., & Dillon, H. (2007). Development of the Listening in Spatialized Noise - Sentences Test (LISN-S). Ear and Hearing, 28(2), 196-211.

Cameron, S., Brown, D., Keith, R., Martin, J., Watson, C., & Dillon, H. (2009). Development of

the North American Listening in Spatialized Noise - Sentences Test (NA LISN-S): Sentence equivalence, normative data, and test-retest reliability studies. Journal of the American Academy of Audiology, 20(2), 128-146.

Chermak, G.D. (2007). Differential diagnosis of (central) auditory processing disorder and attention deficit hyperactivity disorder. In F.E. Musiek & G.D. Chermak (Eds.), Handbook of (central) auditory processing disorder: Auditory neuroscience and diagnosis (Vol. 1, pp. 397-416). San Diego, CA: Plural Publishing.

Chermak, G.D., Bellis, T.J., & Musiek, F.E. (2007). Neurobiology, cognitive science and intervention. In G.D. Chermak & F.E. Musiek (Eds.), Handbook of (central) auditory processing disorder: Comprehensive intervention (Vol. 2, pp. 3-28). San Diego, CA: Plural Publishing.

Chermak, G.D., Hall, J.W., & Musiek, F.E. (1999). Differential diagnosis and management of central auditory processing disorders and attention deficit hyperactivity disorder. Journal of the American Academy of Audiology, 10(6), 289-303.

Chermak, G.D., & Musiek, F.E. (1997). Central auditory processing disorders: New perspectives. San Diego, CA: Singular Publishing Group.

Chermak, G.D., & Musiek, F.E. (2002). Auditory training: Principles and approaches for remediating and managing auditory processing disorders. Seminars in Hearing, 23(4), 297-308.

Chermak, G.D., & Musiek, F.E. (Eds.). (2007). Handbook of (central) auditory processing disorder: Comprehensive intervention (Vol. 2). San Diego, CA: Plural Publishing.

Chermak, G.D., Silva, M.E., Nye, J., Hasbrouck, J., & Musiek, F.E. (2007). An update on professional education and clinical practices in central auditory processing. Journal of the American Academy of Audiology, 18(5), 428-452.

Chermak, G.D., Traynham, W.A., Seikel, J.A., & Musiek, F.E. (1998). Professional education and assessment practices in central auditory processing. Journal of the American Academy of Audiology, 9(6), 452-465.

Chmiel, R., & *Jerger,* J. (*1996*). Hearing aid use, central auditory disorder, and hearing handicap in elderly persons. Journal of the American Academy of Audiology, 7(3), 190-202.

Cohen, W., Hodson, A., O'Hare, A., Boyle, J., Durrani, T., McCartney, E., Mattey, M., Naftalin, L., & Watson, J. (2005). Effects of computer-based intervention through acoustically modified speech (Fast ForWord) in severe mixed receptive-expressive language impairment: Outcomes from a randomized controlled trial. Journal of Speech, Language, and Hearing Research, 48(3), 715-729.

Corbett, B.A., Shickman, K., & Ferrer, E. (2007). Brief report: The effects of Tomatis sound therapy on language in children with autism. Journal of Autism and Developmental Disorders, 38(3), 562-566.

Crandell, C., Smaldino, J., & Flexer, C. (2005). Sound-field amplification: Applications to speech perception and classroom acoustics (2nd ed.). New York, NY: Thomson Delmar Learning.

Cranford, J.L., Boose, M., & Moore, C.A. (1990). Effects of aging on the precedence effect in sound localization. Journal of Speech and Hearing Research, 33(4), 654-659.

Cranford, J.L., Stream, R.W., Rye, C.V., & Slade, T.L. (1982). Detection v discrimination of brief-duration tones: Findings in patients with temporal lobe damage. Archives of Otolaryngology, 108(6), 350-356.

Cunningham, J., Nicol, T., Zecker, S.G., Bradlow, A., & Kraus, N. (2001). Neurobiologic responses to speech in noise in children with learning problems: Deficits and strategies for improvement. Clinical Neurophysiology, 112(5), 758-767.

Dalebout, S.D., & Stack, J.W. (1999). Mismatch negativity to acoustic differences not differentiated behaviorally. Journal of the American Academy of Audiology, 10(7), 388-399.

de Bode, S., Sininger, Y., Healy, E.W., Mathern, G.W., & Zaidel, E. (2007). Dichotic listening after cerebral hemispherectomy: Methodological and theoretical observations. Neuropsychologia, 45(11), 2461-2466.

DeLuca, J. (2005). Fatigue, cognition, and mental effort. In J. DeLuca (Ed.), Fatigue as a window to the brain (pp. 37-57). Cambridge, MA: MIT Press.

Divenyi, P.L., & Haupt, K.M. (1997). Audiological correlates of speech understanding deficits in elderly listeners with mild-to-moderate hearing loss. I. Age and lateral asymmetry effects. Ear and Hearing, 18(1), 42-61.

Dublin, W. (1976). Fundamentals of sensorineural auditory pathology. Springfield, IL: Charles C. Thomas.

Dublin, W. (1986). Central auditory pathology. Otolaryngology - Head and Neck Surgery, 95(3 Pt. 2), 363-424.

Educational Audiology Association (1997). Auditory integration therapy [Position Statement]. Retrieved from http://www.edaud.org/displaycommon.cfm?an=1&subarticlenbr=4

Eriks-Brophy, A., & Ayukawa, H. (2000). The benefits of sound field amplification in classrooms of Inuit students of Nunavik: A pilot project. Language, Speech, and Hearing Services in Schools, 31, 324-335.

Fifer, R.C., Jerger, J.F., Berlin, C.I., Tobey, E.A., & Campbell, J.C. (1983). Development of a dichotic sentence identification (DSI) test for use in hearing impaired adults. Ear and Hearing, 4(6), 300306.

Fisher, L.I. (1976). Fisher Auditory Problem Checklist. Cedar Rapids, IA: Grant Wood Area Educational Agency.

Fisher, L.I. (1985). Learning disabilities and auditory processing. In R.J. Van Hattam (Ed.), Administration of speech language services in schools: A manual (pp. 231-290). San Diego, CA: College-Hill Press.

Flexer, C., Millin, J.P., & Brown, L. (1990). Children with developmental disabilities: The effect of sound field amplification on word identification. Language, Speech, and Hearing Services in Schools, 21, 177-182.

Furst, M., Aharonson, V., Levine, R.A., Fullerton, B.C., Tadmor, R., Pratt, H., Polyakov, A., & Korczyn, A.D. (2000). Sound lateralization and interaural discrimination. Effects of brainstem infarcts and multiple sclerosis lesions. Hearing Research, 143(1-2), 29-42.

Gates, G.A., Anderson, M.L., Feeney, M.P., McCurry, S.M., & Larson, E.B. (2008). Central auditory dysfunction in older persons with memory impairment or Alzheimer dementia. *Archives of Otolaryngology Head and Neck Surgery,* 134(7), 771-777.

Geffner, D., & Ross-Swain, D. (2006). The Listening Inventory. Novato, CA: Academic Therapy Publications.

Ghazanfar, A.A., & Schroeder, C.E. (2006). Is neocortex essentially multisensory? Trends in Cognitive Science, 10(9), 278-285.

Gillam, R., Crofford, J., Gale, M., & Hoffman, L. (2001). Language change following computer-assisted language instruction with Fast ForWord or Laureate Learning Systems software. American Journal of Speech-Language Pathology, 10(3), 231-247.

Gillam, R.B., Loeb, D.F., Hoffman, L.M., Bohman, T., Champlin, C.A., Thibodeau, L., Widen, J., Brandel, J., & Friel-Patti, S. (2008). The efficacy of Fast For Word language intervention in school-age children with language impairment: A randomized controlled trial. Journal of Speech, Language, and Hearing Research, 51(1), 97-119.

Golding, M., Carter, N., Mitchell, P., & Hood, L.J. (2004). Prevalence of central auditory processing (CAP) abnormality in an older Australian population: The Blue Mountains hearing study. Journal of the American Academy of Audiology, 15(9), 633–642.

Golding, M., Mitchell, P., & Cupples, L. (2005). Risk markers for the graded severity of auditory processing abnormality in an older Australian population: The Blue Mountains hearing study. Journal of the American Academy of Audiology, 16(6), 348–356.

Gravel, J.S. (1994). Auditory integration training: Placing the burden of proof. American Journal of Speech-Language Pathology, 3, 25-29.

Griffiths, T.D. (2002). Central auditory pathologies. British Medical Bulletin, 63(1), 107-120.

Griffiths, T.D., Dean, J.L., Woods, W., Rees, A., & Green, G.G.R. (2001). The Newcastle Auditory Battery (NAB): A temporal and spatial test battery for use on adult naïve subjects. Hearing Research, 154(1-2), 165-169.

Hall, J.W. (2007). New handbook of auditory evoked responses. Boston, MA: Allyn & Bacon.

Hall, J.W., & Johnston, K.N. (2007). Electroacoustic and electrophysiologic auditory measures in the assessment of (central) auditory processing disorder. In F.E. Musiek & G.D. Chermak (Eds.), Handbook of (central) auditory processing disorder: Auditory neuroscience and diagnosis (Vol. 1, pp. 287-317). San Diego, CA: Plural Publishing.

Hall, J.W., & Mueller, H.G. (1997). Audiologists' desk reference: Diagnostic audiology-principles, procedures and practices (Vol. 1). San Diego, CA: Singular Publishing Group.

Hall, L., & Case-Smith, J. (2007). The effect of sound-based intervention on children with sensory processing disorders and visual-motor delays. The American Journal of Occupational Therapy, 61(2), 209-215.

Hällgren, M., Larsby, B., Lyxell, B., & Arlinger, S. (2001). Cognitive effects in dichotic speech testing in elderly persons. Ear and Hearing, 22(2), 120-129.

Harris, D.P., & Hall, J.W. (1990). Feasibility of auditory event-related potential measurement in brain injury rehabilitation. Journal of the American Auditory Society, 11(5), 340-350.

Hayes, E.A., Warrier, C.M., Nichol, T.G., Zecker, S.G., & Kraus, N. (2003). Neural plasticity following auditory training in children with learning problems. Clinical Neurophysiology, 114(4), 673-684.

Hoge, C.W., McGurk, D., Thomas, J.L., Cox, A.L., Engel, C.C., & Castro, C.A. (2008). Mild traumatic brain injury in US soldiers returning from Iraq. The New England Journal of Medicine, 358(5), 453-463.

Hugdahl, K., Heiervang, E., Ersland, L., Lundervold, A., Steinmetz, H., & Smievoll, H. (2003). Significant relation between MR measures of planum temporale area and dichotic processing of syllables in dyslexic children. Neuropsychologia, 41(6), 666-675.

Hugdahl, K., & Wester, K. (1992). Dichotic listening studies of hemispheric asymmetry in brain

damaged patients. International Journal of Neuroscience, 63(1-2), 17-29.

Humes, L.E., Coughlin, M., & Talley, L. (1996). Evaluation of the use of a new compact disc for auditory perceptual assessment in the elderly. Journal of the American Academy of Audiology, 7(6), 419-427.

Hurley, A., & Hurley, R.M. (2007). Differential diagnosis of (central) auditory processing disorder. In F.E. Musiek & G.D. Chermak (Eds.), Handbook of (central) auditory processing disorder: Auditory neuroscience and diagnosis (Vol. 1, pp. 347-346). San Diego, CA: Plural Publishing.

Hurley, R.M., & Musiek F.E. (1997). Effectiveness of three central auditory processing (CAP)

tests in identifying cerebral lesions. Journal of the American Academy of Audiology, 8(4), 257-262.

Japaridze, G., & Shakarishvili, R., & Kevanishvili, Z. (2002). Auditory brainstem, middle-latency, and slow cortical responses in multiple sclerosis. Acta Neurologica Scandinavia, 106(1), 47-53.

Jerger, J. (1998). Controversial issues in central auditory processing disorders. Seminars in Hearing, 19(4), 393-400.

Jerger, J., Alford, B., Lew, H., Rivera, V., & Chmiel, R. (1995). Dichotic listening, event-related potentials, and interhemispheric transfer in the elderly. Ear and Hearing, 16(5), 482-498.

Jerger, J., Chmiel, R., Allen, J., & Wilson, A. (1994). Effects of age and gender on dichotic sentence identification. Ear and Hearing, 15(4), 274-286.

Jerger, J., & Jerger, S. (1974). Auditory findings in brain stem disorders. Archives of Otolaryngology, 99(5), 342-350.

Jerger, J., & Jerger, S. (1975). Clinical validity of central auditory tests. International Journal of Audiology, 4(3), 147-163.

Jerger, J., Moncrieff, D., Greenwald, R., Wambacq, I., & Seipel, A. (2000). Effect of age on interaural asymmetry of event-related potentials in a dichotic listening task. Journal of the American Academy of Audiology, 11(7), 383-389.

Jerger, J., & Musiek, F. (2000). Report of the consensus conference on the diagnosis of auditory processing disorders in school-aged children. Journal of the American Academy of Audiology, 11(9), 467-474.

Jerger, S., & Jerger, J. (1984). Pediatric Speech Intelligibility Test: Manual for Administration. St. Louis, MO: Auditec.

Jerger, S., Johnson, K., & Loiselle, L. (1988). Pediatric central auditory dysfunction: Comparison of children with confirmed lesions versus suspected processing disorders. American Journal of Otology, 9(Suppl.), 63-71.

Jirsa, R.E. (1992). The clinical utility of the P3 AERP in children with auditory processing disorders. Journal of Speech and Hearing Research, 35(4), 903-912.

Jirsa, R.E. & Clontz, K.B. (1990). Long latency auditory event-related potentials from children with auditory processing disorders. Ear and Hearing, 11(3), 222-232.

Johnson, K.L., Nicol, T., & Kraus, N. (2005). Brainstem response to speech: A biological marker of auditory processing. *Ear and Hearing,* 26(5), 424-434.

Johnson, K.L., Nicol, T.G., Zecker, S.G., & Kraus, N. (2007). Auditory brainstem correlates of perceptual timing deficits. *Journal of Cognitive Neuroscience,* 19(3), 376-385.

Johnston, K.N., John, A.B., Kreisman, N.V., Hall, J.W., & Crandell, C.C. (2009). Multiple benefits of personal FM system use by children with auditory processing disorder. International Journal of Audiology, 48(6), 371-383.

Karlsson, A.K., & Rosenhall, U. (1995). Clinical application of distorted speech audiometry.

Scandinavian Audiology, 24(3), 155-160.

Katz, J. (1962). The use of staggered spondaic words for assessing the integrity of the central auditory nervous system. Journal of Auditory Research, 2, 327-337.

Katz, J., Johnson, C., Brander, S., Delagrange, T., Ferre, J., & King, J., et al. (2002). Clinical and research concerns regarding the 2000 APD consensus report and recommendations. Audiology Today, April/May, 14–17.

Keith, R. (1984). Interpretation of the Staggered Spondaic Word Test. Ear and Hearing, 4(6), 287-292.

Keith, R. (2000). SCAN-C: Test for Auditory Processing Disorders in Children-Revised. San Antonio, TX: The Psychological Corporation.

Keith, R. (2009a). SCAN-3:A Tests for Auditory Processing Disorders in Adolescents and Adults. San Antonio, TX: Pearson.

Keith, R. (2009b). SCAN-3:C Tests for Auditory Processing Disorders for Children, San Antonio, TX: Pearson.

Kelly, D.A. (1995). Central auditory processing disorders: Strategies for use with children and adolescents. San Antonio, TX: Communication Skill Builders.

Kileny, P., Paccioretti, D., & Wilson, A.F. (1987). The effects of cortical lesions on middle latency auditory evoked responses (MLR). Electroencephalography and Clinical Neurophysiology, 66(1-2), 108-120.

Killion, M.C., Niquette, P.A., Gudmundsen, G.I., Revit, L.J., & Banerjee, S. (2004). Development of a quick speech-in-noise test for measuring signal-to-noise ratio loss in normal-hearing and hearing-impaired listeners. Journal of

Acoustical Society of America, 116(4 Pt. 1), 2395-2405.

Kimura, D. (1961). Cerebral dominance and the perception of verbal stimuli. Canadian Journal of Psychology, 15(3), 166-171.

Knight, R.T., Hillyard, S.A., Woods, D.L., & Neville, H.J. (1980). Effects of frontal and temporal-parietal lesions on the auditory evoked potential in man. Electroencephalography and Clinical Neurophysiology, 50(1-2), 112-124.

Knight, R.T., Scabini, D., Woods, D.L., & Clayworth, C.C. (1988). The effects of lesions superior temporal gyrus and inferior parietal lobe on temporal and vertex components of the human AEP. Electroencephalography and Clinical Neurophysiology, 70(6), 499-509.

Knight, R.T., Scabini, D., Woods, D.L., & Clayworth, C.C. (1989). Contributions of the temporal-parietal junction to human auditory P3. Brain Research, 502(1), 109-116.

Kolb, B. (1995). Brain plasticity and behavior. Mahwah, NJ: Lawrence Erlbaum.

Kolb, B., & Whishaw, I.Q. (2008). Fundamentals of human neuropsychology (6th ed.). New York: Macmillan.

Kraus, N., McGee, T., Carrell, T., King, C., Littman, T., & Nicol, T. (1994). Discrimination of speech-like contrasts in the auditory thalamus and cortex. *Journal of the Acoustical Society of America,* 96(5 Pt. 1), 2758-2768.

Kraus, N., McGee, T.J., Carrell, T.D., Zecker, S.G., Nicol, T.G., & Koch, D.B. (1996). Auditory neurophysiologic responses and discrimination deficits in children with learning problems. *Science,* 273(5277), 971-973.

Kraus, N., McGee, T., Sharma, A., Carrell, T. & Nicol, T. (1992). Mismatch negativity event-related potential elicited by speech stimuli. *Ear and Hearing,* 13(3), 158-164.

Kraus, N., Özdamar, Ö., Hier, D., & Stein, L. (1982). Auditory middle latency responses (MLRs) in patients with cortical lesions. *Electroencephalography and Clinical Neurophysiology,* 54(3), 275-287.

Krishnamurti, S. (2001). P300 auditory event-related potentials in binaural and competing

conditions in adults with central auditory processing disorders. Contemporary

Issues in Communication Sciences and Disorders, 28, 40-47.

Kujala, T., Karma, K., Ceponiene, R., Belitz, S., Turkkila, P., Tervaniemi, M., & Näätänen, R. (2001). Plastic neural changes and reading improvement caused by audiovisual training in reading-impaired children. Proceedings of the National Academy of Sciences of the United States of America, 98(18), 10509-10514.

Kurdziel, S., Noffsinger, D., & Olsen, W. (1976). Performance by cortical lesion patients on 40% and 60% time-compressed materials. Journal of the American Audiology Society, 2, 3-7.

Landau, W.M., & Kleffner, F.R. (1957). Syndrome of acquired aphasia with convulsive disorder in children. Neurology, 7(8), 523-530.

Lynn, G.E., Gilroy, J., Taylor, P.C., & Leiser, R.P. (1981). Binaural masking-level differences in neurological disorders. Archives of Otolaryngology, 107(6), 357-362.

Martin, B.A., Tremblay, K.L., & Korczak, P. (2008). Speech evoked potentials: From the laboratory to the clinic. Ear and

Hearing, 29(3), 285-313.

Mazzoni, D., & Dannennberg, R. (1999). Audacity, Version 1.2.6a. Retrieved from http://audacity.sourceforge.net/about/credits

McPherson, D. (1996). Late potentials of the auditory system. San Diego, CA: Singular Publishing Group.

Merzenich, M., & Jenkins, W. (1995). Cortical plasticity, learning and learning dysfunction. In B. Julesz & I. Kovacs (Eds.), Maturational windows and adult cortical plasticity: SFI studies in the sciences of complexity (Vol. XXIII, pp. 247-272). Reading, PA: Addison-Wesley.

Meyers, J.E., Roberts, R.J., Bayless, J.D., Volkert, K., & Evitts, P.E. (2002). Dichotic listening: Expanded norms and clinical application. Archives of Clinical Neuropsychology, 17(1), 79-90.

Moncrieff, D., McColl, R.W., & Black, J.R. (2008). Hemodynamic differences in children with dichotic listening deficits: Preliminary results from an fMRI study during a cued listening task. Journal of the American Academy of Audiology, 19(1), 33-45.

Moncrieff, D.W., & Wertz, D. (2008). Auditory rehabilitation for interaural asymmetry: Preliminary evidence of improved dichotic listening performance following intensive training. International Journal of Audiology, 47(2), 84-97.

Moore, D. (2006). Auditory processing disorder (APD): Definition, diagnosis, neural basis, and intervention. Audiological Medicine, 4(1), 4-11.

Moore, D.R. (2007). Auditory processing disorders: Acquisition and treatment. Journal of Communication Disorders, 40(4), 295-304.

Moore, D.R., Halliday, L.F., & Amitay, S. (2009). Use of auditory learning to manage listening problems in children. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1515), 409-420.

Moore, D.R., Rosenberg, J.F., & Coleman, J.S. (2005). Discrimination training of phonemic contrasts enhances phonological processing in mainstream school children. Brain and Language, 94(1), 72-85.

Mueller, H.G., Beck, W.G., & Sedge, R.K. (1987). Comparison of the efficiency of cortical level speech tests. Seminars in Hearing, 8(3), 279-298.

Musiek, F.E. (1983). The results of three dichotic speech tests on subjects with intracranial lesions. Ear and Hearing, 4(6), 318-323.

Musiek, F.E. (1999). Habilitation and management of auditory processing disorders: Overview of selected procedures. Journal of the American Academy of Audiology, 10(6), 329-342.

Musiek, F.E., & Baran, J.A. (2002). Central auditory evaluation of patients with neurological involvement. In J. Katz (Ed.), Handbook of clinical audiology (5th ed., pp. 532-544). Baltimore, MD: Lippincott Williams and Wilkins.

Musiek, F.E., & Baran, J.A. (1996). Amplification and the central auditory nervous system. In M. Valente (Ed.), Hearing aids: Standards, options, and limitations (pp. 407-437). New York, NY: Thieme Medical Publishers.

Musiek, F.E., & Baran, J.A. (2007). The auditory system: Anatomy, physiology, and clinical correlates. Boston, MA: Allyn & Bacon.

Musiek, F.E., Baran, J.A., & Pinheiro, M. (1990). Duration pattern recognition in normal subjects and in patients with cerebral and cochlear lesions. Audiology, 29(6), 304-313.

Musiek, F.E., Baran, J.A., & Pinheiro, M.L. (1992). P300 results in patients with lesions of the auditory areas of the cerebrum. Journal of the American Academy of Audiology, 3(1), 5-15.

Musiek, F.E., Baran, J.A., & Pinheiro, M.L. (1994). Neuroaudiology: Case studies. San Diego, CA: Singular Publishing Group.

Musiek, F.E., Baran, J.A., & Shinn, J. (2004). Assessment and remediation of an auditory processing disorder associated with head trauma. Journal of the American Academy of Audiology, 15(2), 117-132.

Musiek, F.E., Baran, J.A., Shinn, J.B., Guenette, L., Zaidan, E., & Weihing, J. (2007). Central deafness: An audiological case study. International Journal of Audiology, 46(8), 433-441.

Musiek, F.E., Bellis, T.J., & Chermak, G.D. (2005). Nonmodularity of the CANS: Implications for (central) auditory processing disorder. American Journal of Audiology, 14(2), 128-138.

Musiek, F., Charette, L., Kelly, T., Lee, W., & Musiek, E. (1999). Hit and false-positive rates for the middle latency response in patients with central nervous system involvement. Journal of the American Academy of Audiology, 10(3), 124-132.

Musiek, F.E. & Chermak, G.D. (2009, November). Diagnosis of TBI in (C)APD: Psychophysical and electrophysiological approaches, ASHA Leader. Retrieved from http://www.asha.org/Publications/leader/2009/091124/CAPD.htm

Musiek, F.E., & Chermak, G.D. (2008). Testing and treating (C)APD in head injury patients. The Hearing Journal, 61, 36-38.

Musiek, F.E., & Chermak, G.D. (1994). Three commonly asked questions about central auditory processing disorders: Assessment. American Journal of Audiology, 3, 23-27.

Musiek, F.E., Chermak, G.D., & Weihing, J. (2007). Auditory training. In G.D. Chermak, & F.E. Musiek (Eds.). Handbook of (central) auditory processing disorder: Comprehensive Intervention (Vol. 2, pp. 77-106). San Diego, CA: Plural Publishing.

Musiek, F.E., Chermak, G.D., Weihing, J.A., Zappulla, M., & Nagle, S. (submitted). Sensitivity, specificity, and efficiency of established central auditory processing test batteries. International Journal of Audiology,

Musiek, F.E., Gollegly, K.M., & Baran, J.A. (1984). Myelination of the corpus callosum in learning disabled children: Theoretical and clinical correlates. Seminars in Hearing, 5(3), 231-242.

Musiek, F.E., Gollegly, K.M., Kibbe, K.S., & Verkest-Lenz, S.B. (1991). Proposed screening test for central auditory disorders: Follow-up on the dichotic digits test. American Journal of Otolaryngology, 12(2), 109-113.

Musiek, F.E., Kibbe, K., & Baran, J.A. (1984). Neuroaudiological results from split-brain patients. Seminars in Hearing, 5(3), 219-229.

Musiek, F.E., & Lee, W.W. (1995). The auditory brainstem response in patients with brain stem or cochlear pathology. Ear and Hearing, 16(6), 631-636.

Musiek, F.E., & Lee, W.W. (1998). Neuroanatomical correlates to central deafness. Scandinavian Audiology, 49(Suppl.), 18-25.

Musiek, F.E., & Pinheiro, M.L. (1987). Frequency patterns in cochlear, brainstem, and cerebral lesions. Audiology, 26(2), 79-88.

Musiek, F.E., & Schochat, E. (1998). Auditory training and central auditory processing disorders: A case study. Seminars in Hearing, 19(4), 357-366.

Musiek, F.E., Shinn, J.B., Jirsa, R., Bamiou, D.E., Baran, J.A, & Zaidan, E. (2005). The GIN (Gaps-in-Noise) Test performance in subjects with and without confirmed central auditory nervous system involvement, Ear and Hearing, 26(6), 608-618.

Musiek, F.E., Wilson, D.H., & Pinheiro, M.L. (1979). Audiological manifestations of “split-brain” patients. Journal of the American Auditory Society, 5(1), 25-29.

Myklebust, H.R. (1954). Auditory disorders in children: A manual for differential diagnosis. New York, NY: Grune & Stratton.

Näätänen, R., Paavilainen, P., Rinne, T., & Alho, K. (2007). The mismatch negativity (MMN) in basic research of central auditory processing: A review. Clinical Neurophysiology, 118(12), 2544-2590.

Neijenhuis, K., Tschur, H., & Snik, A. (2004). The effect of mild hearing impairment on auditory processing tests. Journal of the American Academy of Audiology, 15(1), 6-16.

Neuss, D., Blair, J., & Viehweg, S. (1991). Sound field amplification: Does it improve word recognition in a background of noise for students with minimal hearing impairments? Educational Audiology Monograph, 2, 43-52.

O’Hara, B. (2007, April). The listening questionnaire: Effective screening for APD? Poster presented at the annual convention of the American Academy of Audiology, Denver, CO.

Olsen, W.O., Noffsinger, D., & Kurdziel, S. (1975). Speech discrimination in quiet and in noise by patients with peripheral and central lesions. Acta Otolaryngologica, 80(5-6), 375-382.

Palmer, C.V., Nelson, C.T., & Lindley, G.A. (1998). The functionally and physiologically plastic adult auditory system. Journal of the Acoustical Society of America, 103(4), 1705-1721.

Pattyn, N., Neyt, X., Henderickx, D., & Soetens, E. (2008). Psychophysiological investigation of vigilance decrement: Boredom or cognitive fatigue? Physiology and Behavior, 93(1-2), 369-378.

Peña, E.D., Spaulding, T.J., & Plante, E. (2006). The composition of normative groups and diagnostic decision making: Shooting ourselves in the foot. American Journal of Speech-Language Pathology, 15(3), 247-254.

Phillips, D.P., & Farmer, M.E. (1990). Acquired word deafness and the temporal grain of sound representation in the primary auditory cortex. Behavioural Brain Research, 40(2), 85-94.

Pichora-Fuller, M.K. (2003). Cognitive aging and auditory information processing. International Journal of Audiology, 42(Suppl. 2), 2S26-30.

Pressley, M., Johnson, C.J., & Symons, S. (1987). Elaborating to learn and learning to elaborate. Journal of Learning Disabilities, 20(2), 76-91.

Putter-Katz, H., Adi-Bensaid, L., Feldman, I., & Hildesheimer, M. (2008). Effects of speech in noise and dichotic listening intervention programs on central auditory processing disorders. Journal of Basic & Clinical Physiology & Pharmacology, 19(3-4), 301-316.

Richard, G.J. (2007). Cognitive-communicative and language factors associated with (central) auditory processing disorder: A speech-language perspective. In F.E. Musiek & G.D. Chermak (Eds.), Handbook of (central) auditory processing disorder: Auditory Neuroscience and diagnosis (Vol. 1, pp. 397-416). San Diego, CA: Plural Publishing.

Richard, G. & *Ferre*, J. (*2006*). Differential Screening Test for Processing. East Moline, IL: LinguiSystems.

Robbins, A.M., Renshaw, J.J., Miyamoto, R.T., Osberger, M.J., & Pope, M.L. (1988). Minimal Pairs Test. Indianapolis: Indiana University School of Medicine.

Robey, R. (2004, April). Levels of evidence. ASHA Leader, 5.

Rodriguez, G.P., *DiSarno,* N.J., & *Hardiman,* C.J. (1990). Central auditory processing in normal-hearing elderly adults. Audiology, 29(2), 85-92.

Rosenberg, G.G. (2002). Classroom acoustics and personal FM technology in management of auditory processing disorders. Seminars in Hearing, 23(4), 309-317.

Rosenberg, G.G. (2005). Sound field amplification: A comprehensive literature review. In C. Crandall, J. Smaldino, & C. Flexer (Eds.), Sound field amplification: Applications to speech perception and classroom acoustics (2nd ed., pp. 72-111). New York, NY: Thompson Delmar Learning.

Rosenberg, G.G., Blake-Rahter, P., Heavener, J., et al. (1999). Improving classroom acoustics (ICA): A three-year FM sound field classroom amplification study. Journal of Educational Audiology, 7, 8-28.

Rosenberg, P.E. (1972). The test battery approach. In J. Katz (Ed.), Handbook of clinical audiology (pp. 271-279). Baltimore, MD: Lippincott Williams and Wilkins.

Russo, N.M., Nicol, T.G., Zecker, S.G., Hayes, E.A, & Kraus, N. (2005). Auditory training improves neural timing in the human brainstem. Behavioural Brain Research, 156(1), 95-103.

Sackett, D.L., & Straus, S.E. (1998). Finding and applying evidence during clinical rounds: The „evidence cart“. The Journal of the American Medical Association, 280(15), 1336-1338.

Sackett, D.L., Straus, S.E., Richardson, W.S., Rosenberg, W., & Haynes, R.B. (2000). Evidence-based medicine: How to practice and teach EBM (2nd ed.). London: Churchill Livingstone.

Scherg, M., & von Cramon, D. (1986). Evoked dipole source potentials of the human auditory cortex. Electroencephalography and Clinical Neurophysiology, 65(5), 344-360.

Schochat, E., Musiek, F.E., Alonso, R., & Ogata, J. (in press). MLR differentiated children behaviorally diagnosed with (C) APD from matched controls. Brazilian Journal of Medical and Biological Research,

Schow, R.L., Chermak, G.D., Seikel, J.A., Brockett, J.E., & Whitaker, M.M. (2006). Multiple Auditory Processing Assessment. St. Louis, MO: Auditec.

Sharma, A., Dorman, M.F., & Spahr, A.J. (2002). Rapid development of cortical auditory evoked potentials after early cochlear implantation. Neuroreport, 13(10), 1365-1368.

Shehata-Dieler, W., Shimizu, H., Soliman, S.M., & Tusa, R.J. (1991). Middle latency auditory evoked potentials in temporal lobe disorders. Ear and Hearing, 12(6), 377-388.

Shinn, J.B., Chermak, G.D., & Musiek, F.E. (2009). GIN (Gaps-In-Noise) Performance in the pediatric population. Journal of the American Academy of Audiology, 20(4), 229-238.

Shinn, J.B., & Musiek, F.E. (2007). The auditory steady state response in individuals with

neurological insult of the central auditory nervous system. *Journal of the American Academy of Audiology,* 18(10), 826-845.

Sibatini, A. (1980). The Japanese Brain. Science, 80, 23-27.

Shina, S.O. (1959). The role of the temporal lobe in hearing. Unpublished master's thesis. McGill University, Montreal, Quebec.

Sinha, Y., Silove, N., Wheeler, D., & Williams, K. (2006). Auditory integration training and other sound therapies for autism spectrum disorders: A systematic review. Archives of Disease in Childhood, 91(12), 1018-1022.

Singer, J., Hurley, R.M., & Preece, J. (1998). Effectiveness of central auditory processing tests with children. American Journal of Audiology, 7, 1-12.

Smoski, W.J., Brunt, M.A., & Tannahill, J.C. (1992). Listening characteristics of children with central auditory processing disorders. Language, Speech and Hearing Services in Schools, 23, 145-152.

Song, J.H., Banai, K., Russo, N.M., & Kraus, N. (2006). On the relationship between speech- and non-speech evoked brainstem responses in children. Audiology & Neurotology, 11(4), 233-241.

Soysal, A., Atakli, D., Atay, T., Altintas, H., Baybas, S., & Arpaci, B. (1999). Auditory event-related potentials (P300) in partial and generalized epileptic patients. Seizure, 8(2), 107-110.

Spaulding, T.J., Plante, E., & Farinella, K.A. (2006). Eligibility criteria for language impairment: Is the low end of normal always appropriate? Language, Speech and Hearing Services in Schools, 37, 61-72.

Stach, B., Loiselle, L., Jerger, J. et al. (1987). Clinical experience with personal FM assistive listening devices. Hearing Journal, 40(10), 24-30.

Stach, B.A., Spretnjak, M.L., & Jerger, J. (1990). The prevalence of central presbycusis in a clinical population. Journal of the American Academy of Audiology, 1(2), 109-115.

Sweetow, R.W., & Sabes, J.H. (2006). The need for and development of an adaptive Listening and Communication Enhancement (LACE) Program. Journal of the American Academy of Audiology, 17(8), 538-558.

Syntrillium Software Corporation (2002). Cool Edit Pro. Version 2.0. Retrieved from hhtp://www.adobe.com/special/products/audition/syntrillium.html

Sykes, S., Tucker, D., & Herr, D. (1997). Aural rehabilitation and graduate audiology programs. Journal of the American Academy of Audiology, 8(5), 314-321.

Tallal, P., Miller, S., Bedi, G., Byma, G., Wang, X., Nagarajan, S.S., Schreiner, C., Jenkins, W.M., & Merzenich, M.M. (1996). Language comprehension in language-learning impaired children improved with acoustically modified speech. Science, 271(5245), 81-84.

Temple, E., Deutsch, G.K., Poldrack, R.A., Miller, S.L., Tallal, P., Merzenich, M.M., & Gabrieli, J.D. (2003). Neural deficits in children with dyslexia ameliorated by behavioral remediation: Evidence from functional MRI. Proceedings of the National Academy of Sciences of the United States of America, 100(5), 2860-2865.

Thibodeau, L. (2007). Computer-based auditory training for (central) auditory processing disorder. In G.D. Chermak & F.E. Musiek (Eds.), Handbook of (central) auditory processing disorder: Comprehensive intervention (Vol. 2, pp. 167-206). San Diego, CA: Plural Publishing.

Tonnquist-Uhlén, I. (1996). Topography of auditory evoked long-latency potentials in children with severe language impairment: The P2 and N2 components. Ear and Hearing, 17(4), 314-26.

Tremblay, K. (2007). Training-related changes in the brain: Evidence from human auditory evoked potentials. Seminars in Hearing, 28(2), 120-132.

Tremblay, K.L., Billings, C., & Rohila, N. (2004). Speech evoked cortical potentials: Effects of age and stimulus presentation rate. Journal of the American Academy of Audiology, 15(3), 226-237.

Tremblay, K.L., & Kraus, N. (2002). Auditory training induces asymmetrical changes in cortical neural activity. Journal of Speech, Language, and Hearing Research, 45(3), 564-572.

Tremblay, K., Kraus, N., & McGee, T. (1998). The time course of auditory perceptual learning: Neurophysiological changes during speech-sound training. Neuroreport, 9(16), 3557-3560.

Turner, R.G., & Hurley, A. (2009). Evaluating a model to predict protocol performance. Journal of the American Academy of Audiology, 20(10), 644-651.

Turner, R.G., Robinette, M.S., & Bauch, C.D. (1999). Clinical decisions. In F.E. Musiek & W.F. Rintelmann (Eds.), Contemporary perspectives in hearing assessment (pp. 437-464). Boston, MA: Allyn & Bacon.

Vanniasegaram, I., Cohen, M., & Rosen, S. (2004). Evaluation of selected auditory tests in school-aged children suspected of auditory processing disorders. Ear and Hearing, 25(6), 586-597.

Warrier, C.M., Johnson, K.L., Hayes, E.A., Nicol, T., & Kraus, N. (2004). Learning impaired children exhibit timing deficits and training-related improvements in auditory cortical responses to speech in noise. Experimental Brain Research, 157(4), 431-441.

Weiss, D., & Dempsey, J.J. (2008). Performance of bilingual speakers on the English and Spanish versions of the Hearing in Noise Test (HINT). Journal of the American Academy of Audiology, 19(1), 5-17.

Wepman, J.M., & Reynolds, W.M. (1986). Wepman's Auditory Discrimination Test (2nd ed.). Los Angeles, CA: Western Psychological Services, Inc.

Westerhausen, R., Woerner, W., Kreuder, F., Schweiger, E., Hugdahl, K., & Wittling, W. (2006). The role of the corpus callosum in dichotic listening: A combined morphological and diffusion-tensor MRI study. Neuropsychology, 20(3), 272-279.

Wible, B., Nicol, T., & Kraus, N. (2005). Correlation between brainstem and cortical auditory processes in normal and language-impaired children. *Brain,* 128(Pt. 2), 417-423.

Willeford, J., & Burleigh, J. (1985). Handbook of central auditory processing disorders in children. Orlando, FL: Grune and

Stratton.

Wilson, R.H., Preece, J.P., Salamon, D.L., Sperry, J.L., & Bornstein, S.P. (1994). Effects of time compression and time compression plus reverberation on the intelligibility of Northwestern University Auditory Test No. 6. Journal American Academy of Audiology, 5(4), 269-277.

Wright, B.A., & Sabin, A.T. (2007). Perceptual learning: How much daily training is enough? Experimental Brain Research, 180(4), 727-736.

Yakovlev, P.I., & Lecours, A.R. (1967). The myelogenetic cycles of regional maturation of the brain. In A. Minkowski (Ed.), Regional development of the brain in early life (pp. 3-70). Oxford, England: Blackwell.

APPENDIX A. LEVELS OF EVIDENCE (MODIFIED FROM ROBEY, 2004).

Class 1: Most rigorous (e.g., double bind, prospective, randomized clinical trials, time series, and meta analyses)

Class 2: Quasi-experimental research (e.g., non-randomized, prospective, and retrospective designs with control groups)

Class 3: Observations studies with controls (case studies, cohort studies, retrospective studies; e.g., database/registry studies)

Class 4: Descriptive (i.e., observational studies without controls)

Class 5: Expert clinical opinion, consensus, standards for practice, etc.