CHAPTER 6

Screening for (Central) Auditory Processing Disorder

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As will be discussed in Chapter 7, a thorough assessment includes a battery of behavioral and physiological tests, often spanning multiple testing sessions. The intensity and complexity of the diagnostic process mandates the need for a screening instrument that will indicate individuals at risk for (central) auditory processing disorder ([C]APD) prior to initiation of assessment. The screening process proposed here uses behavioral tests for referral purposes for diagnostic testing. The tests reviewed as potential screening measures do not comprise an exhaustive list. All the measures reviewed have been selected because they represent three primary auditory processing domains reflected in recent conference and work group reports (ASHA, 2005; Jerger & Musiek, 2000) and almost all the tests have been examined in at least one factor analysis study that demonstrated its loading on one of these domains. Other potentially useful screening measures that have not been involved in a factor analysis (e.g., Gaps-In-Noise; Musiek et al., 2005) have been omitted. This chapter reflects upon the costs and benefits associated with screening, examines available screening tools, and makes recommendations based on the currently accepted theoretical model of (C)APD and recent recommendations from the Bruton Conference and ASHA (Jerger & Musiek, 2000; ASHA, 2005).

The following material addresses audiologic/speech-language screening for (C)APD, and accordingly is jointly written by an audiologist and a speech-language pathologist. This material represents a new, experimental hybrid screening approach that we believe holds promise for clinical use. Because (C)APD assessment should be within

the context of a team of professionals (e.g., audiologist, speech-language pathologist, educator, psychologist, medical professional, parent, etc.), we assume that other professionals may have their own screening processes and that, at some point in the assessment process, this group of professionals would meet to discuss the audiologist's diagnosis of (C)APD, the need for further evaluation, and the plan for intervention. As part of the screening process, we discuss questionnaires that draw information from other key players, and we assume that the audiologist and/or speech-language pathologist involved in the screening process might use these questionnaires to gather information from psychologists, medical professionals, parents, teachers, and the individual of concern about potential comorbidities, such as attention deficit hyperactivity disorder (ADHD), learning disability (LD), reading problems, autistic spectrum disorder, and speech/language deficit (S/LD) as these disorders relate to behaviors suggesting (C)APD. This information becomes especially important if the child goes on to a full diagnostic workup.

Screening for children (or adults) at risk for (C)APD should be completed by the audiologist or speech-language pathologist in a manner similar to pure-tone screening in the school setting (probably at the 3rd grade level), or, alternatively, may be completed following referral by teacher, parent, or other professional. Clearly, a screening protocol is important in helping to minimize the attendant problems for the individual with (C)APD, for parents, educators, and other involved professionals. Screening is important to allow timely intervention which should minimize distress and maximize communicative, educational, and social function (Chermak, 1996; Musiek, Gollegly, Lamb & Lamb, 1990).

/H1/ Costs and Benefits

Any discussion about the ability of a test to perform its function must be based on the knowledge that there is no *gold standard* behavioral assessment instrument, so this necessarily reduces the certainty with which sensitivity and specificity can be identified. Ultimately, the sensitivity and specificity of central auditory tests should be "derived from patients with known, anatomically confirmed central auditory dysfunction and used as a guide to identify the presence of central auditory dysfunction in children and adults suspected of (C)APD" (ASHA, 2005, p. 9). The above philosophical approach has been fundamental to the screening process recommended in this chapter in that from the beginning of our work we have followed the recommendations of Musiek and Chermak (1994), which were based on anatomically confirmed central auditory dysfunction. Table 6-1 illustrates issues related to sensitivity and specificity (Dawson & Trapp, 2004; Ingelfinger, Mosteller, Thibodeau & Ware, 1987).

Insert Table 6-1 about here

Sensitivity is the ability of a test to identify the presence of a disorder when one is actually present. Note that this ability has no implicit relationship to misidentifying those who do not have the disorder. Thus, the perfectly sensitive test of (C)APD will never miss in diagnosing someone with (C)APD (t**rue positive identification**), but does not "care" about whether it is inadvertently misdiagnosing someone who does not have the disorder (f**alse positive identification**). That is, sensitivity is only related to positive outcome. By virtue of its highly sensitive nature, a test with high sensitivity will have a

low false negative rate, where false negative is the group of people who have the disorder but are not identified by the test as having the disorder.

High sensitivity is a laudable goal in all cases, but comes at a cost. If one looks simply at economic outcome, overidentification of a disorder results in delivering services not only to those with the disorder but also to those for whom the services are unneeded. High sensitivity without regard for false positives is expensive in economic and human terms. However, high sensitivity is good even if specificity suffers a bit because if one uses a diagnostic test follow-up, the false positives will be detected and not passed on.

Specificity is the ability of a test to identify correctly those individuals who do not have the dysfunction. In this case, the test with perfect specificity will have no cases in the False Positive cell, because no one has been identified who does not have the disorder. The cost of this quality is that, because of the test's cautionary approach to misidentification, the number of true positives declines. A test with high specificity is conservative about identifying a disorder, whereas a test with high sensitivity is liberal in identifying the disorder. The perfectly specific test unerringly identifies all individuals who do not have (C)APD. It maximizes cases in the True Negative category without regard to the number of false negatives that will arise from its conservatism.

The reality, of course, is that both over- and underdiagnosis have their costs. Overdiagnosis (likely with high sensitivity) wastes resources by providing unneeded treatment, whereas underdiagnosis (likely with high specificity) incurs the risks related to the disorder itself: Underdiagnosing breast cancer at an early stage vastly increases the 5-year mortality for the disease, whereas underdiagnosing hay fever will have little impact

on mortality. Overdiagnosing breast cancer will result in increases in the costs associated with lumpectomy or biopsy, which are traumatic but represent relatively small costs compared with loss of life. Overdiagnosing hay fever results in relatively small costs in medication incurred by the patient. Thus, the costs associated with the playoff between true positives and false positives are always associated with the risks of failure to identify (i.e., loss of health). The costs associated with true negatives and false negatives are similarly decided in terms of the costs associated with excessive diagnosis (e.g., loss of economic resources).

When the true outcome is knowable (such as in cancer assessment and diagnosis, where signs and symptoms will ultimately prove the accuracy of the diagnosis), one can calculate the sensitivity of a measure. This implies not only an agreed-upon definition of the disorder but a means of identifying the disorder accurately, both of which have been demonstrated for (C)APD with a reasonable degree of certainty in recent years (ASHA, 2005). A focused and neurobiologically anchored definition of (C)APD has been promulgated by the American Speech-Language-Hearing Association through an extensive peer-review process (ASHA, 2005). Furthermore, efficient behavioral and electrophysiologic tests and procedures are available to diagnose (C)APD in the case of known, identifiable lesions (Chermak & Musiek, 1997; Hendler, Squires, & Emmerich, 1990; Jerger, Johnson, & Loiselle, 1988; Musiek, Shinn, Jirsa, Bamiou, Baran, & Zaidan, 2005; Rappaport Gulliver, Phillips, van Dorpe, Maxner, & Bhan, 1994). However, in the great majority of school children and in many adults who appear to have a form of (C)APD based on behavioral tests and questionnaires, there is no demonstrable lesion. Electrophysiologic and topographic mapping studies are revealing differences, however,

in the neurophysiologic representation of auditory stimuli in the CANS of subjects with behaviorally diagnosed (C)APD and listening and learning problems (see for example Jerger et al., 2002; King, Warrier, Hayes, & Kraus, 2002; Musiek, Charette, Kelly, Lee, & Musiek, 1999; Purdy, Kelly, & Davies, 2002; Warrier, Johnson, Hayes, Nicol, & Kraus, 2004)

The difficulty of electrophysiologically tracking behavioral test changes and myelination changes was underscored in a study by Schochat and Musiek (2006). (AUTHOR: please add Schochat & Musiek to referenc list) They examined the maturation course of the frequency and duration pattern tests and the middle latency response (MLR) in 150 normal participants ranging from 7 to 16 years of age. Results showed increased performance with increasing age for both behavioral tests up to age 12. However, there was no significant change across this age range for MLR on either latency or amplitude measures. Similarly, the P300 was inferior to two behavioral tests in identifying individuals with confirmed central nervous system lesions (Hurley & Musiek, 1997). In contrast, Musiek, Baran, and Pinheiro (1992) (AUTHOR: add Musiek, Baran & Pinheiro to reference list) reported significant differences in P300 latency and amplitude between adults with confirmed CANS lesions and normal controls. Other studies also have demonstrated the ability of late evoked potentials to identify dysfunction in the central auditory nervous system. For example, Jerger et al. (2002) studied dizygotic (i.e., fraternal) twin girls, one presenting symptoms of (C)APD. They demonstrated that event-related potential activation patterns differentiated the twins better than the behavioral tests (i.e., dichotic listening within an oddball paradigm) performed concurrently, which showed essentially no performance difference between

the girls. Similarly, Estes, Jerger, and Jacobson (2002) demonstrated the limitations of behavioral tests (i.e., auditory gap detection and auditory movement detection) relative to the capability of event-related potentials (i.e., N1-P2 and P300) in differentiating normal versus poor listeners.

Thus, it appears that, although there are accepted physiologic measures of (C)APD, and some may hold potential as screening measures, when it comes to school screening where advanced electrophysiological equipment will not be readily available, other screening tools must be used. Nonetheless, sensitivity and specificity of screening tests may be derived ultimately from patients with known, confirmed central auditory dysfunction (ASHA, 2005). Albeit with some reservations, it is our opinion that interim steps to estimate sensitivity and specificity may use performance outside normal limits on behavioral tests that are expected to have predictive power. (See Spaulding, Plante, and Farinella [2006] for discussion of the potential adverse consequences of such an approach.) These established behavioral tests will need to be used to estimate the efficiency (i.e., sensitivity and specificity) of screening procedures until a true gold standardelec—trophysiological or neuroimaging procedures—has demonstrated the efficiency of these behavioral tests with a large sample of school-aged children.

Comment:

Sensitivity of a test is defined as the proportion of true positives that are identified (e.g., 5) compared with the total of those with the disorder (e.g., 7), yielding a percentage (e.g., 71 %). The specificity of a test is defined as the proportion of true negatives that are identified (e.g., 12) as compared with the total number who do not have the disorder (e.g., 48), yielding a percentage (e.g., 25%). A 71% hit rate is laudable, but a specificity

of 25% is expensive. It is within this context of costs and benefits that we must enter the examination of screening instruments for (C)APD.

It is important to note that the prevalence of a disease or disorder influences a test's efficiency. If the disorder occurs rarely in the population (as does [C]APD estimated as 2-3% based on Chermak & Musiek, 1997), the chances of detecting it are low—even by a test with high sensitivity. In this same situation, the chances of persons passing the test would be high because most people do not have the disorder. Hence, this test's positive predictive value (defined as the ratio of those with the disorder who were identified by the test to the total number of those failing the test) would be low and its negative predictive value would be high. Clinicians must be aware of the approximate prevalence of a disorder in order to have some general idea of a test's positive and negative predictive values. (See Chapter 7 for further discussion of the concepts of test sensitivity and efficiency within the framework of clinical decision analysis.)

/H2/Sensitivity Versus Validity

Before leaving the topic of test sensitivity and specificity, it is important to note the relationship of these concepts to test **validity**. Ascertaining that a test is valid (i.e., measures what is purported to measure) does not imply that the test is sensitive (or specific) (Musiek & Chermak, 2007). AUTHOR: Clarify If chapter 1 of this volume is meant? Or add to reference list.) In contrast to validity, sensitivity and specificity speak to the degree to which a valid measure of a domain reliably identifies a bivalent state—disease/nondiseased. (See Chapter 1 for additional discussion of this distinction.)

/H1/Screening Instruments for (C)APD

Screening instruments for (C)APD, therefore, should identify a high proportion of those with the disorder by use of a relatively brief and "inexpensive" procedure that is easy to administer and optimally, not influenced by hearing loss, language, cognition, culture or other nonauditory factors. The Bruton conference summary (Jerger & Musiek, 2000) suggested a 10-minute procedure. Our experimental hybrid screening procedure uses 2.5 times that much time, which we consider practical in a school situation where a mass screening might logically be used only once during the primary grades. Screening is "allowed" to have lower expectations concerning specificity than sensitivity. Indeed, as noted above, a high sensitivity rate, *at times*, takes its toll in reduced specificity; however, this is acceptable with a screening measure because the next step is to follow up with a more extensive diagnostic test battery. Hence, one must keep in mind that a screening procedure leads to an in-depth diagnostic assessment before a final diagnosis can be made. The cost of performing further diagnostic testing is low relative to the cost of failure to identify. Thus, a screening test for (C)APD should err on the side of increased sensitivity even at the cost of diminished specificity.

The ASHA (1996, 2005) guidelines for (C)APD state that a diagnosis of (C)APD requires demonstration of a deficiency in one or more of the following areas: (a) auditory pattern recognition, (b) temporal processing (including temporal integration, discrimination, ordering, and masking), (c) auditory performance with degraded acoustic signals (monaural low redundancy), (d) auditory performance with competing acoustic signals (including dichotic listening), (e) auditory discrimination, and (f) localization and/or lateralization (binaural interaction). The guidelines do not differentiate verbal and nonverbal acoustic stimuli. A significant issue in using a screening measure for (C)APD

is that the screener should be able to identify a "fail" in each of those categories to ensure inclusion, since a "true" fail in any *one* of those categories signals the presence of (C)APD (sensitivity). An alternative strategy is to use failure on one of the cardinal signs of (C)APD (e.g., temporal processing) as an indicator of the need for assessment in all domains. This alternative strategy assumes the interdependence across categories of central auditory processes (and their underlying neural substrate). Although such overlap might be anticipated, our research has suggested that these processes can in fact present independently; therefore, we consider a one-test screener inferior to the hybrid process described here. We recognize the downside of using a multiple-test screener: greater sensitivity may be achieved at the cost of poorer specificity.

We recommend behavioral strategies for screening (C)APD. The success of these behavioral tests is used to determine sensitivity and specificity. Following this, we suggest questionnaire surveys can be used successfully to provide good, functional information on an individual's everyday problems. Once a diagnosis is made, such questionnaire information can assist intervention planning, in counseling/collaborating with parents or other professionals, and even contribute as an outcome measure to monitor across the course of therapy. Physiologic tests are usually used in a more detailed assessment, but not in screening. The authors' hybrid strategy using behavioral tests is presented at the culmination of this review. The most widely used instrument for the behavioral approach to screening (C)APD is the *SCAN: A Screening Test for Auditory Processing Disorders* (Keith, 2000a, 2006b). The SCAN is discussed in a later section of this chapter.

Questionnaire surveys typically are presented to caregivers or teachers, and observable signs are identified that serve as indicators of disorder or dysfunction. Although questionnaires have advantages in sampling behaviors characteristic of (C)APD filtered through the eyes of someone familiar with the individual and revealing information that can be used to guide treatment decisions, they present limitations as well. Questionnaires are affected by the subjectivity and biases of the respondent. Questions can be unclear, misleading, too broad, or inappropriate. Also, questionnaires can be too lengthy, leading to inaccurate information due to respondent fatigue or lack of interest (Maxwell & Satake, 2006). The questionnaire described later in this chapter has items carefully selected to avoid many of these problems. Furthermore, all referrals are based on the behavioral test and not on the questionnaire, which is used only to supplement and contextualize the behavioral test findings after a diagnostic battery confirms (C)APD.

/H2/Behavioral Tests

Instruments for screening and assessment should reflect the ASHA (1996, 2005) definition of (C)APD. Table 6-2 presents potential tests and subtests that reflect the seven ASHA (2005) test areas derived from the six central auditory processes identified above. These seven test areas are: auditory pattern/temporal tests, monaural low redundancy tests, binaural/dichotic speech tests, binaural interaction tests, auditory discrimination tests, electroacoustical tests, and electrophysiologic tests.

Insert Table 6-2 about here

The SCAN seems to dominate clinical use as a screening instrument, although it only looks at two (i.e., binaural /dichotic tests and monaural low redundancy tests) of the seven test areas listed above. Several other tests and procedures have been proposed as screening tools for (C)APD including the Selective Auditory Attention Test (SAAT), dichotic digits, frequency patterns, gap detection, and so forth (Bellis, 2003; Cherry, 1980; Jerger & Musiek, 2000; Musiek, 1983). Some authors have proposed a requirement to isolate auditory from other sensory modalities in assessment of (C)APD (Cacace & McFarland, 1998). Nonetheless, indications are that no single test or procedure produces acceptable results on a sensitivity/specificity basis (in our work, sensitivity did not ever reach 50% with any of the screeners listed above including SCAN; Domitz & Schow, 2000), and, as stated in the ASHA (2005) *Position Statement on (C)APD*, completely separating sensory modalities is "neurophysiologically untenable" (p. 4).

It is the present authors' view that one cannot adequately screen without addressing each of the ASHA auditory test domains that have accepted, commonly used methods for testing, which therefore requires a screening battery. This was reinforced by Chermak (1996) who said in speaking of diagnostic testing ". . . given the complexity of the central auditory nervous system, it is unlikely that any one behavioral test can be considered the definitive test of central auditory function. Hence, a comprehensive pediatric central auditory evaluation requires a battery of tests . . ." (p. 211). For these same reasons we think screening requires a battery. Use of a battery runs somewhat counter to the definition of screening in terms of ease and time of administration, but we suggest it is justified and necessary in this case. Based on the Bruton Conference (Jerger

& Musiek, 2000) and relevant discussions following that conference, we conclude there is evidence that three commonly used test domains exist for (C)APD and that all three can and should be measured using behavioral tests (Chermak, 2001). These three, with recommended acronyms, are (a) **auditory pattern/temporal ordering** (APTO) tests, (b) **monaural separation closure** (MSC), (c) **binaural integration/binaural separation** (BIBS) tests (see "Auditory Domain" in Table 6-2). ASHA (2005) identified four other test areas (i.e., discrimination tests, binaural interaction tests, electroacoustical tests, electrophysiologic tests), but there are very few data to indicate the utility of screening in these areas for (C)APD, nor are there tools available in many of these areas that could be used in most screening settings, including the schools.

This chapter is organized to address the three generally accepted areas of measurement (i.e., APTO, MSC, and BIBS tests). If and when there are data to support additional areas, the same general strategy can be used to involve four, five, or more areas of concern. Below we summarize *representative* behavioral instruments based upon this categorization. Much of the material reported below in this three-pronged approach was developed from an initial recommendation by Musiek and Chermak (1994). They based their recommendations on the relationship between behavioral tests and known pathophysiology, although they also state that, in children, (C)APD is "usually a benign medical condition" (p. 24), The four tests suggested by Musiek and Chermak were focused on the three areas of measurement mentioned above, and formed the basis of MAPA. Using this framework, we have used their four recommended tests to develop normative data. The "outliers" from the normative data (i.e., those falling 2 SD below the mean) are identified as having (C)APD (i.e., our quasi behavioral *gold*

standard). In short, this strategy has been used in a preliminary way to define children with (C)APD in an effort to develop a behavioral *gold standard*. This work involved a series of studies using factor analysis and careful test design strategies (Conlin 2003; Domitz & Schow, 2000; Schow, et al., 2000, 2006; Schow & Chermak, 1999; Shiffman, 1999; Summers, 2003). In this process the Multiple Auditory Processing Assessment (MAPA) test battery was developed. Using one test (or one from the same domain in the case of the Selective Auditory Attention Test [SAAT]) recommended by Musiek and Chermak (1994) in each of three domains (SAAT, Pitch Patterns [PP], Dichotic Digits [DD]) and comparing these to the four test behavioral *gold standard* (which included Competing Sentences in addition to the SAAT, PP, and DD), we were able to obtain 90% sensitivity. In contrast, when using one test alone, we obtained no better than 40% sensitivity (obtained with the SAAT), with sensitivity of 30% obtained with the PP and 30% with the DD (Domitz & Schow, 2000). Inasmuch as (C)APD was here defined in terms of these four neurobiologically anchored behavioral tests, specificity was in all cases 100%.

Although the conclusions here are based on the behavioral test sensitivity and specificity of our work and on a behavioral quasi *gold standard*, we would argue that these findings underscore the need for a battery approach and are defensible as a measure of diagnostic accuracy. We simply have to start somewhere and although a behavioral standard involves some assumptions, we think it is a reasonable approach and is similar to the approach used in language disorders. Swets (1988) has written some of the key articles on diagnostic accuracy and the gold standard. He explains that different diagnostic fields may use a variety of approaches and all have certain limitations, but by

using the fundamental principles (sensitivity and specificity data) scientists in each field can work together (not in isolation) on defining the standards and test strategies and ". . . contribute mutually to their general refinement" (p. 1291). More details about the battery are summarized below. Because of the importance of **factor analysis** in test design nearly all the representative tests described below and in Table 6-2 have at least one study that supports the factor grouping.

(PLACE FOOTNOTE FROM P. 17 NEAR BOLDED FACTOR ANALYSIS ABOVE)

/H3/APTO: (Auditory Pattern Temporal Ordering)

- MAPA Pitch Pattern Test
- MAPA TAP Test
- MAPA Duration Patterns
- MAPA Fusion Test

/H4/MAPA Pitch Pattern Test.

This test was modeled after the Frequency Patterns (FP) Test (Musiek & Pinheiro, 1987). The FP Test reflects the ASHA (1996, 2005) temporal component of auditory pattern recognition, and has been a staple for screening in (C)APD. The test consists of 120 test sequences, each made of three tones. Two of the tones are the same and one varies, and the subject is required to declare the pattern to the tester (verbally, by humming, or by pointing to a visual analog).

The MAPA **Pitch Patterns** Test (Schow, Chermak, Seikel, Brockett, & Whitaker, 2006) is derived from Pinheiro (1977). This test introduces high and low pitches binaurally in a four-tone series, and the subject identifies the pattern by verbalizing (e.g.,

high-high-low-high). The four-tone sequence was used instead of Pinheiro's original three-tone sequence because of a ceiling effect identified by Shiffman (1999) and Neijenhuis, Snik, Priester, van Kordenoordt, and van den Broek (2000). A four-tone pattern avoids the ceiling effect observed using the three-tone pattern and results in the same factor structure as the three-tone pattern test. Nonetheless, the additional tone is likely to exert greater demands on memory and reversals are scored correctly to avoid a floor effect. Summers (2003) tested 119 children using the entire MAPA battery, and results were subjected to factor analysis. This test loaded strongly (0.74) to the APTO domain).

/H4/MAPA Tap Test (Schow et al., 2006)

The MAPA Tap Test was developed upon the suggestion of Charles Berlin who has used it clinically for years and found it extremely useful (personal communication). It is purported to test temporal resolving dimensions of the auditory system. In this test, a series of tapping sounds is presented with an interval of 120 ms between taps. (Although the interstimulus interval is large in the context of temporal resolution, and may therefore burden working memory, the Tap Test factors strongly with at least one other test in the APTO domain.) Three series of taps are presented to the listener. After each series the listener must indicate the number of taps heard. The total number of test taps is 30, so that a raw score is based on the sum of the subject's estimate of number of taps. The test proved surprisingly sensitive to (C)APD, loading firmly (0.50) on the APTO domain (Summers, 2003). (Factor loadings on TAP were even larger, i.e., 0.75. when Duration Patterns and AFT-R were included in the tests factored)

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*Factor analysis was reported in the development of the SCAN (Keith, 1986) and in the development of a Dutch (C)APD battery of tests (Neijenhuis et al., 2000). The obvious advantage of Factor Analysis is that the power of this statistical procedure allows many tests to be grouped in terms of the underlying factor which is being measured and similar tests can be grouped together. Through a series of five major studies, a strong, consistent, underlying factor structure has emerged supporting each of the tests used for the three domains, although in some tests a few minor factors were found. In the development of MAPA, both exploratory and confirmatory procedures were used that makes the test development even stronger (Keith, 1986; Neijenhuis et al., 2000; Schow et al., 2000, 2006).

/H4/MAPA Durations Pattern Test (Schow, et al., 2006).

This is based on the Musiek et al. (1990) three-tone **Duration Patterns** test, but in this case groups of four-tone series are presented binaurally to the subject. Duration of the tones is randomly varied between short and long. The subject's task is to verbally report the series in the order that the tones were presented (e.g., "long-short-long-long"). Summers (2003) reported only a modest loading on APTO (.36) based on 119 subjects. Accordingly, the Pitch Pattern and Tap Test were selected in the MAPA battery to measure the temporal domain because of their more favorable factor loading compared to Duration Patterns and Gap Detection.

/H4/MAPA Fusion Test (Schow, et al., 2006).

The **Auditory Fusion** Test-Revised (AFT-R) (McCroskey & Keith, 1996) purports to examine the resolving capacity of the auditory nervous system of listeners. It is actually

a test of **temporal resolution**, as are **gap detection** tests. The AFT-R provides the listener with pairs of gated tonal stimuli that are separated by millisecond-level intervals of silence. Because the expected temporal resolution is 1 to 2 ms (Green, 1973), listeners who fail to recognize the gaps at smaller intervals are *assumed* to be at risk for (C)APD.

The RGDT is a revised version of the Auditory Fusion Test-Revised (AFT-R) (McCroskey & Keith, 1996). Keith (2001) notes that the purpose of the Random Gap Detection Test (RGDT) is to identify deficits related to temporal function of the auditory system as they relate to phonologic processing deficits, auditory discrimination, receptive language, and reading. Similar to the AFT-R, the RGDT measures temporal resolution through determination of the smallest time interval between two temporally proximate stimuli. The listener attends to a series of paired stimuli as the silent interval between the pairs changes in duration. The task of the listener is to report whether the percept was of one or two tones. See Chermak and Lee (2005) for a comparison of tests of temporal resolution.

The MAPA Fusion Test (Schow, et al., 2006) uses the final subtest of the RGDT, which utilizes click stimuli of 230 μsec duration followed by interstimulus intervals of 0 to 40 ms presented in random order. Each stimulus pair is separated by an interstimulus interval of 4.5 seconds. The clicks were derived from a 1-ms compression (positive) section of white noise (Keith, 2001). Temporal resolution was only weakly loaded on the MSC domain (-0.29) during exploratory analysis, and did not provide increased sensitivity in identification of children at risk for (C)APD (Summers, 2003). Although the Bruton Conference summary (Jerger & Musiek, 2000) recommended the use of either a gap detection test or dichotic digits for screening (C)APD, we have found

only dichotic digits to be supported by factor findings in two school screening studies in tests on almost 200 children (Domitz & Schow, 2000; Summers, 2003). With reference to gap detection, the Bruton group did not specifically recommend any of the currently marketed versions (i.e., RGDT or AFT-R), about which questions were raised regarding validity and reliability.

/H3/MSC (Monaural Separation Closure)

- MAPA mSAAT
- MAPA SINCA (Speech in Noise for Children & Adults)
- SCAN Auditory Figure Ground (AFG) and Filtered Words (FW) subtests
- QuickSIN/BKB-SIN tests
- Time-altered/Time-compressed speech
- Performance-Intensity functions (PI-PB)

/H4/MAPA mSAAT: (MAPA Monaural Selective Auditory Attention Test; Schow et al., 2006)

The original SAAT (Cherry 1980, 1992) is normed for children between the ages of 4 and 9 years, and takes 8 minutes to administer. The test compares the ability of the patient to recognize monosyllabic words without competing background (speech recognition task) and embedded in background of competing high-interest speech. Both target and competition stimuli were recorded by the same speaker, thereby eliminating speaker recognition cues. The signal-to-competition ratio is 0 dB. Normative data provide evidence that it accurately screens in 90% of children who have been identified as having

a learning disability, which Cherry claimed related to an underlying, but undiagnosed, (C)APD (Cherry, 1992).

The MAPA Monaural-SAAT (MAPA mSAAT; Schow et al., 2006) follows the construction of SAAT (Cherry, 1980, 1992). It requires the subject to listen for a word selected from the WIPI word list that is embedded in competing background noise of high-interest speech, recorded by the same speaker. This version utilizes only monaural stimulation, as a monaural low-redundancy test was needed more than a binaural test and dichotic stimulation did not improve the sensitivity of the test. This test loaded strongly (0.74) on the MSC domain in factor analysis (Summers, 2003).

/H4/MAPA **Speech in Noise for Children and Adults** (MAPA SINCA) (Schow et al., 2006).

Monosyllabic PBK words were recorded and subjects were required to listen for the primary stimulus embedded in competing four-speaker babble background. With each stimulus the signal to noise ratio decreases, ultimately to 0 dB. This test loaded strongly (0.72) in the MSC domain in factor analysis (Summers, 2003).

Because the mSAAT and SINCA both load (i.e., the correlation between each variable and the various factors) strongly on the monaural factor (0.74 and 0.72, respectively) there is support for using these two tests to screen for the monaural domain. However, SCAN AFG and SCAN FW have been shown also to load strongly (0.68 and 0.55, respectively) with mSAAT (0.78 and 0.74 for left and right ear mSAAT: Domitz & Schow, 2000). It is presumed that QuickSIN/BKB-SIN, which are nearly identical to SINCA, would also load in the monaural domain. Thus, these four other tests should

provide good backup for testing the MSC domain. This is helpful because form equivalency and test-retest reliability on mSAAT and SINCA need improvement, and until they are better in this area it would seem prudent to supplement mSAAT and SINCA with other tests. QuickSIN/BBK-SIN, fortunately have many equivalent forms and should have strong utility in the MSC domain.

/H4/SCAN AFG & FW (Keith, 1995, 2000a, 2000b)

The SCAN-C consists of four subtests (Auditory Figure-Ground [AFG], Filtered Words [FW], Competing Words [CW], Competing Sentences [CS]) and represents two of the ASHA (1995, 2005) deficit areas, with AFG and FW falling into the MSC domain, and CW and CS being categorized as BIBS, based on factor studies (Domitz & Schow, 2000; Schow & Chermak, 1999). The purpose of the SCAN-C is to determine possible disorders of the central nervous system, to identify problems in auditory processing ability, and to identify children at risk for (C)APD (Keith, 1995, 2000).

The AFG subtest uses monosyllabic words with a competing multitalker babble to assist in identification of children who experience difficulty separating signal from noise. The FW subtest uses low-pass filtered (degraded) monosyllabic words in an attempt to identify children who are unable to re-create the missing information. The original SCAN was normed on 1,035 children in the schools (Keith, 1986), wherein a factor study was reported that supported AFG and FW as loading in the same domain (MSC). Neijenhuis et al. (2000) also found factor support for AFG and FW testing within an MSC domain.

The SCAN takes approximately 20 minutes to administer, but provides a reasonably deep level of screening, and is designed for use with children between the ages of 3 and 11 years. Test-retest reliability of the SCAN is relatively unstable (Amos & Humes, 1998), and administration of the SCAN is sensitive to the administration environment (Emerson, Crandall, Seikel & Chermak, 1997; but see Keith, 1998), but appears to be unbiased with reference to race of the individual being tested (Woods, Peña, & Martin, 2004). Humes, Amos, and Wynne (1998) also noted weaknesses in that the SCAN does not have multiple forms. In addition, the SCAN uses internal consistency coefficients rather than test-retest coefficients to calculate confidence intervals, which results in artificially smaller standard errors of the mean and narrower confidence intervals, leading to classification of more scores as outside normal limits.

The SCAN is highly dependent upon verbal knowledge (Chermak & Musiek, 1997), and thus is limited to English-speaking children. Chermak, Styers, and Seikel (1995) found that the SAAT identified greater numbers of children as at-risk for (C)APD than did the SCAN.

/H4/QuickSIN test/BKB-SIN (QuickSIN Speech in Noise Test, Version 1.3: Etymotic Research, 2001, 2005)

The QuickSIN is designed to assess a subject's ability to listen within a background of noise. The BKB-SIN is a similar test which is appropriate and normed for children (Etymotic, 2005). These tests are designed to rapidly provide a reasonable estimate of the functional signal-to-noise ratio at which an individual can comprehend speech.

QuickSIN/BKB-SIN are very similar to the MAPA SINCA and their use of noise to reduce redundancy places them in the MSC auditory domain category.

/H4/Performance-Intensity functions (PI-PB)

Performance-intensity functions for phonetically balanced words (PI-PB) have been proposed as a means of testing monaural low-redundancy processing (Humes, 2005). Theoretically, the performance-intensity function would improve dramatically as intensity increased, but could reveal deficits in individuals for whom greater redundancy is required. To date, only one study (Humes, 2005) has examined it with relation to auditory processing, and results were equivocal. Nonetheless, the ready ability to generate a PI-PB function through standard audiometric assessment speaks to the need to pursue this as a potential screening instrument.

/H3/ BIBS (Binaural integration, Binaural separation)

- MAPA Dichotic Digits
- MAPA Competing Sentences
- SCAN Competing Words
- Staggered Spondaic Words (SSW)

/H4/MAPA Dichotic Digits

This test presents a different series of digits to each ear simultaneously, with the task being to identify as many numbers as possible. Instructions vary, including requiring

correct order, identification of ear of presentation, or simply listing the numbers heard. Results rely on binaural integration, attention, and auditory memory.

The MAPA **Dichotic Dig**its test (DD: Schow et al., 2006) is derived from Musiek (1983). The original formulation required that two number pairs be presented simultaneously to each ear of the listener, with the subject being required to repeat all four numbers. The MAPA DD employed number triplets presented dichotically, similar to that of Neijenhuis et al. (2000). The subject repeats items from the right ear first, then from the left, following Moncrieff and Musiek (2002). This test loaded strongly (0.67) on the BIBS auditory domain during factor analysis (Summers, 2003). Again, it is important to note that while loading on the same factor suggests that double-digit and triplet pairs both provide some measure of similar processes (the triplet (MAPA) DD probably involves memory to a greater extent than the double-digit DD.

/H4/MAPA Competing Sentences

Willeford (1985) introduced the Competing Sentences Test (CS), and Keith (2000) integrated competing sentences into the SCAN-A. In the MAPA Competing Sentences Test (Schow et al, 2006), two sentences are presented dichotically, and the subject repeats both sentences. This more difficult task was used because of a ceiling effect identified by Shiffman (1999) when only one sentence was repeated. Subjects are required to repeat either the right or the left ear first, and stimuli must be repeated with 100% accuracy to be considered correct. Subjects are not penalized for reversing the order of the sentences as repeated. Due to the greater difficulty of the modified task, 8- to 9-year-old subjects' mean performance was only 41% (*SD* = 14%), . This test loaded strongly (0.65) on the

BIBS auditory domain during factor analysis. Besides the strong factor loading of DD and CS, the work of Domitz and Schow (2000) and Schow, Seikel, Chermak, and Berent (2000) recorded a 0.70 correlation between DD and CS, which strongly supports combining those two tests to derive a measure of the binaural domain (BIBS). DD is thought to involve binaural integration, and because subjects are asked to repeat competing sentences (CS) in a certain order, this appears to be a binaural separation task or some combination of binaural integration and separation.

/H4/ SCAN CW Subtest (Keith, 2000a, 2000b).

The Competing Words subtest is a dichotic task in which words are presented simultaneously to both ears and the child is required to identify both words. Domitz and Schow (2000) reported that the CW subtest loaded onto the BIBS domain. Schow and Chermak (1999) compared results of SCAN CW and Staggered Spondaic Words (SSW: Katz, 1962), revealing that the SSW (left and right Competing SSW scores) were highly related to the CW subtests and all three load on the BIBS domain.

/H4/Staggered Spondaic Word Test: SSW (Katz, 1962)

The SSW is a dichotic task that requires the listener to simultaneously process information presented to both ears. The design of the stimuli is such that the second syllable of one spondee overlaps with the first syllable of its contralateral counterpart. As noted above, Schow and Chermak (1999) found that the SSW loads positively in the BIBS domain.

/H3/Binaural Interaction (Sound localization and lateralization)

Although masking level differences and interaural intensity and interaural time difference tests (i.e., **localization/lateralization**) have been proposed for testing in this domain, there are no known studies which have analyzed the factor structures of these tests.

/H3/Questionnaires

Several **questionnaires** for (C)APD have been devised, based on the assumption that children and adults with the disorder have distinctive behavioral profiles that can provide useful screening information.

/H4/Fisher's Auditory Problems Checklist (Fisher, 1976)

This questionnaire itemizes behaviors such as failure to attend to instructions, the need for repeated instructions, and easy distraction by auditory stimuli. Examination of the questionnaire reveals that the preponderance of items on the questionnaire relate to a language-based deficit (e.g., lack of comprehension of speech at age level). Several questions relate to discrimination ability, directly addressing the ASHA (1996, 2005) criteria, and one reflects degraded processing in a competing acoustic environment. Attentional and memory issues, not reflected in ASHA (1996; 2005), are relatively prominent elements of the questionnaire, as are language abilities.

/H4/Children's Auditory Processing Performance Scale (CHAPPS: Smoski, Brunt, & Tannahill, 1992)

The Children's Auditory Processing Performance Scale (CHAPPS) is a 25-item scale that allows the user to rate behaviors in multiple conditions. Parents and teachers can be used as informants. Smoski et al. (1992) reported variable listening performance for 64 children diagnosed with (C)APD on the basis of failing two or more of a four-test battery comprised of the Staggered Spondaic Word (SSW) Test, and versions of dichotic digits, competing sentences, and pitch patterns. Children with (C)APD demonstrated difficulties in quiet and ideal listening conditions, as well as in competing noise and stressful listening conditions.

/H4/Evaluation of Classroom Listening Behavior (ECLB: VanDyke, 1985)

The ECLB is a rating scale completed by the classroom teacher. It is designed to identify listening and academic problems in children. The listening behavior subtest focuses heavily on attention-based phenomena (e.g., paying attention to oral instruction; off-task behaviors; short attention span), but also includes more specific (C)APD elements, such as following oral instructions and distraction in background of noise. A specific Classroom Listening Behavior subscale elicits response differences based on environment (noise, group, quiet), presence of visual cues, complexity of directions, and distance from speaker. As such, it provides greater detail about specific classroom listening abilities related to (C)APD, and may be a useful broad-spectrum screen for the disorder. That having been said, no research has been identified relating results of ECLB and (C)APD testing.

/H4/Children's Home Inventory for Listening Difficulties (CHILD: Anderson & Smaldino, n.d.)

CHILD is a “family-centered” parent survey that allows parents to assess a child’s listening behavior within the home environment. It may be used to assess listening skills in a child as young as 3 years old and as old as 12. The items focus on hearing difficulty and comprehension in quiet and noisy settings, rather than on specific (C)APD characteristics, but may serve as a broad screen for processing deficit.

/H4/Use of Questionnaires to Differentiate ADHD from (C)APD

Similarities between ADHD and (C)APD provide a source of ongoing unease within the educational and audiological communities. A diagnosis of ADHD is made based upon criteria put forward by the Diagnostic and Statistical Manual (DSM-IV), which provides the definition of ADHD. Within that framework, ADHD is seen as a deficit resulting in inattention, hyperactivity, and/or impulsivity. Some characteristics provided by the DSM-IV guidelines include poor attention, poor listening skills, distraction, and forgetfulness, common characteristics ascribed to individuals with (C)APD. Chermak, Somers, and Seikel (1998) examined the overlap between characteristics ascribed to (C)APD and ADHD by the respective diagnosing professionals, and ferreted out discerning characteristics for each disorder that would serve as components of a questionnaire. See below how these findings in conjunction with other work have been used to create a new questionnaire. This new tool, therefore, provides discriminating elements used by professionals to differentiate the two disorders. See Chapter 15 for discussion of differential diagnosis of (C)APD and ADHD.

/H4/Scale of Auditory Behaviors (SAB) (See Appendix 6A; Conlin, 2003; Shiffman, 1999; Simpson, 1981; Summers, 2003)

The Teacher's Scale of Auditory Behaviors and the Parent's Scale of Auditory Behaviors (Simpson, 1981) were normed on 96 children, ages 4 to 6 years. Domitz and Schow (2000) validated the Teacher's Scale with the 81 participants in their study, including 17 who ultimately were identified as having (C)APD. Shiffman (1999) refined the instrument by identifying the most useful items to contrast the 7 children diagnosed with (C)APD versus the 12 children identified as not having (C)APD. Twelve of these items were found to be congruent with the recommendations of the Bruton group (Jerger & Musiek, 2000), as well as with the findings of Chermak, Somers, and Seikel (1998). These 12 items formed a new questionnaire called the Scale of Auditory Behaviors (SAB) (Conlin, 2006; Schow et al., 2006; Summers, 2003). Summers found that use of the SAB in conjunction with the MAPA provided a functional means of identification of children with auditory processing problems needing attention for (C)APD. In her study, she identified -1.5 SD as providing the best "fail" cutoff for identification of children with, or at risk for, (C)APD. Summers recommended using failure (-2 SD) of one or more subtests of the MAPA and a "fail" on the checklist as requiring follow-up/treatment for (C)APD.

/H2/ Hybrid Screening Solution

Because the SCAN does not include all three auditory domains (APTO, BIBS, MSC), we think it cannot be proposed for screening without adding other tests. We have listed a series of tests in Table 6-2 that are within the three domains mentioned, and have indicated which of these have undergone factor analysis to determine the content validity (Chermak & Schow, 1997; Conlin, 2003; Domitz & Schow, 2000; Shiffman, 1999; Summers, 2003; Neijenhuis, et al, 2000). With Summers, (2003); and Conlin, (2003)— ,

and in our most recent work the present authors have identified a set of six tests that represent each domain, with two tests per area that both strongly factor together, and are readily available as components of the Multiple Auditory Processing Assessment Battery (Schow et al., 2006). All six can be given in about 25 minutes and so we propose screening using all six tests. It is feasible that at some later time only one test will be used in each domain, which will cut the screening time in half.

Because the MAPA has not yet been tested on individuals with confirmed lesions in the CANS, we are unable at present to precisely define sensitivity and specificity in each of the three areas physiologically. This may eventually be possible and if the sensitivity is adequate in all three areas (and with reasonable specificity), this screening process can then be determined to be efficient in that manner. In the meantime, we have chosen to use outliers from normative data (a common method used to diagnose language disorders) on multiple tests in the same domain area as an interim step, recognizing the limitations of such an approach (e.g., see Spaulding et al.. 2006).

Our strategy is to form a hypothesis about failure within each of the three domains based on the two tests and comparative norms for same-aged children. A (C)APD screening result will be based on the number of tests within the domain (1 or 2) for which there are reduced scores (two SDs below the mean) and the number of total domains (1, 2, 3) that show low scores. When the parent or teacher response (both types of input are recommended) of the SAB questionnaire reinforces the behavioral test findings, or there is comorbidity in ADHD, LD, reading, autism, or S/LD, we consider there is an increased urgency but the behavioral test scores alone are used as the basis for diagnostic referral.

We recommend that those with “fail” questionnaire scores but no -2 SD behavioral test problem be followed and retested again in one year.

/H3/Normative Data for Behavioral and Questionnaire Instruments

Following Musiek and Chermak (1994), Domitz and Schow (2000) examined the utility of a four-test battery to screen for (C)APD, based upon the ASHA (1996) criteria for the disorder. The authors screened 81 children using two questionnaires, four behavioral tests (i.e., SAAT, PP, DD, and CS), the SCAN and the Auditory Fusion Test-Revised (1000 and 4000 Hz) (Keith, 2000a, 2000b) Seventeen of the 81 children failed the screening on at least one of the four tests and were on this basis assumed to have CAPD (this was our preliminary *gold standard*). Shiffman (1999) re-examined 7 of the original 17 students who failed using the same four tests, as well as 12 children identified as not having (C)APD. Shiffman's goal was to determine the degree to which the four-battery screener predicted later findings suggestive of (C)APD identified at retest two years later. This study supported the hybrid (behavioral test/questionnaire) approach and resulted in good agreement (83-85%) using the original findings as the standard. In the next phase of this work, the six-test MAPA was normed by Summers for the age groupings from 8 through 11 years, inclusive, and included 119 subjects. There were 14 (12%) found to have performance poorer than -2 SDs on one or more of these tests. Test-retest reliability of the MAPA for 19 children in the 8- to 11-year-old age range was also determined by Summers (2003) (PP = 0.91, CS = 0.86, TAP = 0.77, DD = 0.73, MSAT = 0.67, SINCA = 0.50) and preliminary norms for 12-year-olds and adults also were established. Two forms (A & B) of the MAPA are available (Conlin, 2003). Form equivalency ranged from

moderate for the MSC tests (0.46) to high for the BIBS (0.81) and APTO tests (0.90). An overall correlation coefficient (for the three areas combined) of 0.79 revealed strong interform equivalency for the total battery. The SAB (Appendix A; Schow et al., 2006) was developed as a questionnaire to be used in conjunction with the behavioral screening process. Conlin provided norms (Appendix 6A). The questionnaire is used to support findings of the six-test battery. Thus, the questionnaire score can be used to determine the real-world impact of a potential deficit on an individual, and the behavioral test results can provide information about domain (APTO, MSC, BIBS) and severity (number of domains in which subject is deficient).

/H1/Summary and Conclusion

Although the ability to accurately identify children and adults who have (C)APD remains limited by the nature of the disorder, headway has been made in description of the disorder and in factor study of relevant tests (ASHA 1996, 2005; Chermak, 2001; Jerger & Musiek, 2000; Schow et al., 2006). In this chapter we have clarified the characteristics of (C)APD and condensed them into three currently useful domains, as supported by factor analysis results on over 300 children. We have provided summaries of some behavioral instruments used to screen these auditory domains, and using six of them in a hybrid approach we found a 12% referral rate on 119 school children. Finally, we have provided a questionnaire (SAB) that holds promise to contextualize the behavioral findings and to be used as an outcome measure, after the diagnostic process, if therapy is indicated and completed. These materials, although experimental, provide a basis for a battery screening approach until more basic and clinical research is completed.

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