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Three studies on the assessment and diagnosis of Auditory Processing Disorder (APD) were conducted. The first study measured the failure rate of AP tests (speech and non-speech) and the APD diagnosis rate using four different diagnostic criteria. A retrospective analysis was conducted on test scores of 117 individuals with suspected APD. Failure rate was 3 to 4 times higher on the speech tests than the non-speech tests and consequently, there was a decrease in the diagnosis rate of APD when non-speech tests were included. Based on these findings, it was recommended that test batteries used to diagnose APD should include at least one non-speech test.

The second study questioned whether an adding 2 seconds to the response time in three AP tests would benefit both typically developing students and those with learning disabilities. Learning disabled (LD) and 12 typically developing (TD) children (24 and 12 children, respectively) were administered three AP tests, Dichotic Digits (DD), Duration Pattern Sequence (DPS), and Random Gap Detection (RGD), under standard and extended time conditions. Students with LD improved significantly on the DD and DPS tests in the extended time condition. These findings indicate that adding 2 seconds to response time will significantly reduce the rate of APD diagnosis in students with LD.

The third study investigated whether children with suspected APD are normally distributed between 1 and 2 standard deviations (SDs) below the mean. Retrospective analysis of AP assessments of 98 children did in fact show a normal distribution. Analysis revealed that the measured difference in the sample was not significantly

different from the expected difference of 13.59% between 1 and 2SD. Consistent with AAA and ASHA guidelines, performance below 2 SD on at least two tests should be used to diagnose APD.

THREE STUDIES ON THE ASSESSMENT AND DIAGNOSIS OF AUDITORY PROCESSING DISORDERS

by

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CHAPTER I

STATEMENT OF THE PROBLEM

There is no general consensus among clinicians and researchers on the test battery selection, assessment procedures and diagnostic criteria for auditory processing disorders (APD) (Ferguson, Hall, Riley, & Moore, 2011; Kamhi, 2011; Katz, 1992; Moore, 2006; Schwartz, 2011). The APD diagnostic rate varies depending on which tests are selected (speech test or non-speech test) from the AP test battery (Musiek, Geurkink, & Kietel, 1982; Wilson & Arnott, 2013), short response time and complexity of the test (Schwartz, 2011), and the criterion used to classify participants as pass or fail on the test, e.g., scores 1 or 2 standard deviation (SD) below mean (AAA, 2010; ASHA, 2005; Katz, 1992). The test selection and test administration procedures are not addressed clearly in the clinical practice guidelines provided by the American Academy of Audiology (AAA, 2010) or the guidelines provided by the American Speech and Hearing Association (ASHA, 2005) for the assessment and diagnosis of APD. As a result, clinicians across the country use an individualized approach in assessing and diagnosing APD. This raises a concern among clinicians and researchers about the potential for overdiagnosis and misidentification of individuals for APD.

APD is diagnosed by audiologists who perform a set of tests from the various recommended tests by AAA and ASHA. The failure on at least two tests (scores 2 SD below mean) from an AP test battery is a requirement to diagnose an individual as APD

(AAA, 2010; ASHA, 2005). If failed only one test then the scores have to be 3 SD below mean to diagnose an individual as APD. In the AP assessment battery, individual tests can have different failure rates. AP tests utilize speech as well as non-speech stimuli and it has been reported that the failure rate was higher on speech tests compared to non-speech tests among the individuals suspected of APD (Wilson & Arnott, 2013). It was reported that individuals with language impairment perform poorly on speech tests and perform well on non-speech tests (Moore, 2006); therefore, the use of non-speech tests would help to differentiate language impairments from APD (McArthur, 2009). Consequently, a greater proportion of speech tests within an AP test battery may potentially lead to a higher diagnosis of APD. Currently, the clinical standard of care provides neither specific guidelines in selection of the number of tests in the AP test battery nor recommendations for the types of tests (speech/non-speech).

AP assessment procedures and the validity of the standardized AP tests were questioned by many researchers (Dawes & Bishop, 2009; Cacace & McFarland, 2009). It has been reported that AP tests are sensitive to measures of attention (Cook et al., 1993; Gascon, Johnson, & Burd, 1986), auditory memory (Riccio, Hynd, Cohen, & Molt, 1996) and learning abilities (Gomez & Condon, 1999). AP test procedures involve rapid presentation of auditory stimuli and generally the participant is required to respond verbally. Smaller inter-stimulus-intervals, consistent rapid verbal responses and task complexity increase attention and working memory demands. Some children with learning disabilities (LD) or language-related impairment (LI) fail on AP testing because of the task complexity, rapid nature of the tests, and high attentional and working memory demands rather than a deficit in the neural processing of the auditory stimuli (Coady, Kluender, & Evans, 2005; Marler, Champlin, & Gillam, 2001; Schwartz, 2011). There is a need to modify AP assessment procedures for children with LD/LI in order to differentiate two groups: first, LD/LI children with APD and second, LD/LI children who perform poorly on AP tests due to attentional, memory and motor demands.

In addition to test selection and assessment procedures, there is no consensus about which cutoff scores classify a child as pass or fail on AP tests. Cutoff criteria recommended by AAA and ASHA is different from the cutoff criteria recommended by the Central Test Battery (CTB) developed by Katz (1992). AAA and ASHA consider 2 standard deviations (SD) below the mean score of the typically developing population as failure on AP test. Furthermore, a child has to fail at least two tests in the test battery, to diagnose as APD. If child fails one test, then the score should fall three SDs below the mean to diagnose APD (AAA, 2010; ASHA, 2005). The CTB, one of the most widely used test batteries in the United States (US) to diagnose APD (Chermak, Traynham, Seikel, & Musiek, 1998; Schow & Chermak, 1999), uses 1 SD below the mean as a cutoff score. It is evident that there is no consensus about using cutoff scores among clinicians across the country. Using different cutoff scores to diagnose APD may lead to different APD diagnosis rates.

Purposes of the three studies were:

Study 1: The purpose of this study was to quantify the failure rate of AP tests (speech and non-speech) and to measure the APD diagnosis rate using four different diagnostic criteria in a large sample of participants assessed for APD.

Study 2: This study determined the effect of varying response time on the performance of children with LD on AP tests. This study also considered whether practice affected test performance.

Study 3: The purpose of this study was to determine whether or not the current sample of participants assessed for AP was normally distributed between 1 SD and 2 SD below mean. The study measured the differences in test failure rate and APD diagnostic rate for children using two different cutoff criteria: 1 SD below mean, as recommended by Central Test Battery (CTB) and 2 SD below mean, as recommended by ASHA (2005).

CHAPTER II

REVIEW OF THE LITERATURE

This section provides an overview describing the definition, symptoms and comorbid conditions of APD. Furthermore, the current challenges in assessing APD and modality specific diagnosis of APD is discussed. It also explains two different APD diagnostic criteria, which are used by audiologists in current clinical practice.

Auditory Processing Disorders (APD)

Auditory processing disorder (APD) is a broad term referring to a deficit in neural processing of auditory stimuli within the central auditory nervous system (CANS). The American Speech and Hearing Association's (ASHA) technical report from 2005 defines auditory processing as involving the following skills (ASHA, 2005; Bellis, 2003; Chermak, Musiek, & Craig, 1997).

a) Sound localization (identifying sound source direction and distance) and lateralization (ability to localize to a side);
b) Auditory discrimination (frequency and loudness);
c) Auditory pattern recognition (ability to determine similarities and differences in patterns in the duration, pitch, volume and intervals of the sound stimuli);
d) Temporal aspects of audition (ability to process time related cues in acoustic stimuli), including temporal integration (integrating information

presented serially), temporal discrimination (e.g., temporal gap detection), temporal ordering (connecting information in order of presentation) and temporal masking (ability to detect a sound stimuli before or after masking noise);

e) Auditory performance in competing acoustic signals (including dichotic listening); and

f) Auditory performance with degraded acoustic signals

APD is a deficit demonstrated by the poor performance in one of the above-described skills. Other abilities such as auditory attention, phonological awareness, auditory synthesis and memory for auditory information are reliant on the intact central auditory function and are considered cognitive or language-related functions. Therefore, they are not part of the definition of APD (ASHA, 2005).

APD is a complex and heterogeneous disorder and different combinations of auditory deficits are likely to be associated with different functional symptoms. The same auditory deficit may affect individuals differently depending on bottom up processing (sensory driven) and top down processing (concept driven) abilities. Also, differences in neural development, subtle and obvious neurological disorders and exposure to various environmental conditions may contribute to auditory processing abilities (ASHA, 2005). Individuals with APD frequently report difficulty with speech perception in background noise, auditory discrimination, localization, multiple direction commands (auditory memory), message comprehension, auditory attention, socialization, language difficulties and academics (reading, spelling and writing) (ASHA, 2005; Bellis & Ferre, 1999;

Chermak et al., 1997; Katz, 1992; Riccio, Hynd, Cohen, Hall, & Molt, 1994; Yalcinkaya, Muluk, & Sahin, 2009). Developmental conditions such as attention deficit hyperactivity disorder (ADHD), dyslexia or learning disabilities (LD) and specific language impairment (SLI) are highly comorbid conditions with APD and also share some of the APD symptoms related to listening (ASHA, 2005; Yalcinkaya et al., 2009). However, the correlation between auditory processing abilities and language learning disorders or other higher order disorders is complex. The heterogeneity of APD may contribute to the failure to find a predictive relationship between auditory processing abilities and higher order abilities such as attention and language (Bishop, Carlyon, Deeks, & Bishop, 1999; Watson & Kidd, 2002).

APD and Comorbid Conditions

Attention Deficit Hyperactivity Disorder (ADHD)

Previous studies have explored the performance of children with ADHD on APD measures and found that children with ADHD performed poorly on these measures (Cacace & McFarland, 2009; Keith & Engineer, 1991; Lundlow, Cudahy, Bassich, & Brown, 1983). Lundlow et al. (1983) compared children falling under four categories: 1) hyperactive and language impaired; 2) language impaired but not hyperactive; 3) reading disabled with language impairment and hyperactive; and 4) normal controls. Results indicated that the first three groups performed poorly on APD measures and the performance of the hyperactive groups was the lowest. Approximately 50% of the ADHD kids were diagnosed as having APD (Riccio, 1994).

A high concordance between teacher rating of inattention and poor performance on an AP test (Staggered Spondaic Word test) was reported (Katz, 1962). These findings raise a question: are APD and ADHD a singular disorder? Most of the current assessment tools used for the diagnosis of APD demand attentional and working memory processing. The test procedures are complex and difficult to learn and the tests require rapid auditory processing skills. Shorter response time increases attention load and could be the reason for poor performance of ADHD children on APD tasks and hence, increase the probability of comorbidity (Riccio, 1994).

Some individuals with ADHD reported difficulty with timing. Timing refers to the adjustment of behavior to specific timeframes, the ability to perceive time intervals and predict inter-temporal choices. Timing functions are further sub-classified into motor timing, perceptual timing and temporal foresight (Rubia & Smith, 2004). Motor timing is the adjustment of a behavior or a motor response an externally or internally defined timeframe. Perceptual timing is time estimation and discrimination. Temporal foresight is the ability to make present choices considering the future outcomes. In an extensive review, Noreika et al. (2013) reported that ADHD patients have impaired motor timing, perceptual timing and temporal foresight. The timing deficit could influence the performance of children with ADHD on rapid and timed AP tests (Ludlow et al., 1983).

Language Impairment (LI)

Although there is evidence that language-impaired children have a deficit in auditory processing abilities (McArthur & Bishop, 2004; Tallal & Stark, 1981), there were other studies that did not find this deficit (Bishop, Carlyon, Deeks, & Bishop, 1999;

Helzer, Champlin, & Gillam, 1996). Normal language learning and conceptual processing depends on various sensory mechanisms such as hearing, vision, attention and memory processes (Kamhi, 1993). It was reported that attentional mechanisms play an important role in the poor performance of children with SLI on AP tasks (Helzer et al., 1996).

Impaired temporal processing among children with SLI was reported. Children with SLI required larger inter-stimulus-intervals to achieve an average level of performance compared to age matched normal language children (Lowe & Campbell, 1965). Tallal and other researchers have successfully reproduced results showing that children with SLI and dyslexia show poor processing abilities for rapid acoustic stimuli and for shorter inter stimulus intervals (Tallal, 1980; Tallal & Piercy, 1973). However, it was found that children with SLI perform similarly to age-matched normal language children when the stimulus rate was not rapid (Stark, Tallal, & McCauley, 1988). The deficit was also elicited in visual modality. This deficit was referred to as "neural timing deficit" (Tallal, 1988) and the involvement of higher order attentional processes was suggested.

Learning Disabilities (LD)

Some studies have reported poor auditory processing abilities in children with reading disorders, dyslexia or LDs (Ahissar, Protopapas, Reid, & Merzenich, 2000; Amitay, Ahissar, & Nelken, 2002; Nagarajan et al., 1999; Tallal, 1980). Others have questioned whether children with reading disorders or LDs have APD (Rosen, 2003).

Dyslexic children, despite getting conventional classroom experience, fail to attain the language skills of reading, writing, and spelling that match their intellectual abilities (World Federation of Neurology, 1968). Current research has reported various non-phonological deficits among children with dyslexia, such as reduced speed in information processing (Denckla & Rudel, 1976; Nicolson, 1994), problems in visual processing (Stein, 1989) and problems in motor skills (Rudel, 1985).

Nicolson (1994) studied the reaction time of children with dyslexia for simple selection, selective choice reaction and lexical decision tasks. The author reported that children with dyslexia performed the same as their age mates on a simple selection task whereas the reaction time for selective choice and lexical decision was severely impaired. The author also suggested the factors contributing to the slow reaction time were general processing deficit and linguistic deficit or both. Previous studies have reported that dyslexic children performed more poorly on time bound tests than under the relaxed conditions (Ellis & Miles, 1981; Seymour, 1986). It is also reported that children with dyslexia have a deficit in access to the spoken word which was discovered using the "rapid automatized naming" test (Denckla & Rudel, 1976).

The rapid naming deficit was consistently replicated for the auditory, visual and tactile (palpated) stimuli (Rudel, Denckla, & Broman, 1981; Swanson, 1987). The fact is evident that children with dyslexia will show a deficit on any task that demands continuous access to the spoken language or verbal response (Wolff, Michel, & Ovrut, 1990). This reduced speed of information could be attributed to impaired linguistic processing, global processing such as working memory or a motor timing deficit (Wolff, Cohen, & Drake, 1984). The deficit was further studied to understand the timing control of coordinated motor action in dyslexic children. As per Lashley's classic hypothesis, expressive language needs a neural mechanism of timing and serial order control to coordinate motor action of speech (Lashley, 1937). Dyslexic adolescents and adults were assessed with the nonsense syllable repetition task (two and three syllable strings). It was found that dyslexic adolescents and adults had difficulty with timing precision when they had to pace their response as per the external timing signal, i.e. metronome and they also repeated syllables too slowly with more errors compared to the normal group (Wolff et al., 1990). Another study reported a rate dependent motor deficit among individuals with dyslexia (Wolff, Michel, Ovrut, & Drake, 1990).

Individuals with learning disabilities perform poorly on AP tests. The possible explanations for the poor performance of LD children on rapid auditory tasks are as follows:

1. Motor Deficit (Wolff et al., 1990; Wolff et al., 1990)
2. Language Deficit (Anderson, Brown, & Tallal, 1993; Bishop & Adams, 1990; Denckla & Rudel, 1976; Ellis & Miles, 1981; Seymour, 1986; Wolff et al., 1984)
3. Sluggish Attentional Shift (Hari & Renvall, 2001; Laasonen, Tomma-Halme, Lahti-Nuuttila, Service, & Virsu, 2000; Tallal & Piercy, 1973)
4. Slow reaction time (McGrady & Olson 1970; Montgomery, 2004; Nicolson, 1994)
5. Poor automaticity (Denckla & Rudel, 1974; Denckla & Rudel, 1976; Nicolson, Fawcett, & Dean, 2001; Wolf, 1986)

6. Rapid presentation (Tallal and Piercy, 1973)
7. Attention and working memory demands (Daneman & Carpenter, 1980; McLean & Hitch, 1999; Swanson, 1993)

Modality Specific Diagnosis of APD

For the last two decades, modality specific diagnosis of APD has been emphasized (McFarland & Cacace, 1995). These researchers suggested when diagnosing APD, the deficit should be more pronounced in processing acoustic information and should not be apparent in other sensory modalities (if present then to a lesser degree) (Cacace & McFarland, 1998; Cacace & McFarland, 2013; McFarland & Cacace, 1995). Rosen (2005) argued that it is not reasonable to label poor auditory performance as APD if it results from impaired attention, which is a higher order process that can be differentiated by using analogue tests in other sensory modalities. Of course, there is a possibility of a common cause that leads to both APD and poor attention (for example, a demyelination disease like multiple sclerosis).

The ASHA (2005) statement makes clear that it is inappropriate to label listening difficulties manifested by higher order, cognitive, or global processes as APD. It was suggested that APD for individuals without a known neurological lesion should be redefined as a cognitive disorder rather than a sensory disorder (Moore, Ferguson, Edmondson-Jones, Ratib, & Riley, 2010). Cacace and McFarland (2005) stated that higher order processes such as attention, memory, motivation, underlying cross modal and supramodal interferences could affect any psychophysical measure of APD. They recommended using tasks in multiple modalities, such as a visual analogue of the AP test, to check whether a similar deficit is persistent in other modalities. This approach of analogue testing lacks literature support and seems impractical in a clinical situation (Musiek, Bellis, & Chermak, 2005). Developing a complete analogue test in other modality is difficult. For example, how does one construct a true analogue of frequency discrimination when central mechanism processing the information is different for the auditory and visual systems.

A complete modality-specific diagnostic criterion for APD is difficult. A rigorous assessment of multimodality functioning to differentiate APD from higher order cognitive linguistic disorders is not within the scope of practice of any professional group. The basic cognitive neuroscience has shown that sensory information processing in the brain is influenced by multimodal processes (Calvert et al., 1997; Mottonen, Schurmann, & Sams, 2004; Sams et al., 1991). Evidence of convergent sensory tracks, multi-sensory neurons and neural interfacing demonstrates the integrated and interdependent processing of sensory information that is supported by attention, memory and language representations (Bashford, Riener, & Warren, 1992; Bradlow & Pisoni, 1999; Groenen, 1997; Phillips, 1995).

Musiek et al. (2005) proposed recommendations to reduce the effect of confounding factors such as higher order processes of attention, language and memory: (a) use of non-linguistic stimuli or a stimuli that carries light linguistic load (use of material that needs less linguistic background, for example digits carry less linguistic load compare to sentences); (b) performing intra-subject comparisons (comparing scores within the test), including ear differences (difference between right and left ear), inter-test and cross disciplinary analysis (comparing scores between tests and results from assessment of other modalities) to rule out supramodal effects; (c) use of binaural separation tasks or integration tasks during dichotic listening (e.g., consistent left ear deficit under normal hearing sensitivity conditions is unlikely due to supramodal deficit ; and (d) use of simple response mode (e.g., humming versus a verbal response) (ASHA, 2005; Bellis, 2002, 2003; Bellis & Ferre, 1999; Chermak, Hall 3rd, & Musiek, 1999; Jerger & Musiek, 2000; Musiek et al., 2005). In such a scenario, it is important to come up with an assessment procedure that is clinically feasible. Therefore, there is a need for a modified assessment procedure to reduce the influence of higher order processes on the tasks or tests used to diagnoses APD.

Test Battery Selection

The clinical guidelines developed by the American Academy of Audiology (AAA) and the American Speech and Hearing Association (ASHA) give detailed recommendations about the test principles, types of AP tests and diagnostic criteria (AAA, 2010; ASHA, 2005). AP tests utilize speech as well as non-speech stimuli. In the AP assessment battery, individual tests can have different failure rate. The APD diagnostic rate varies depending on the test selection in AP test battery (Musiek et al., 1982; Wilson & Arnott, 2013). Among individuals with APD failure rate has been reported higher on speech tests compared to non-speech tests (Wilson & Arnott, 2013), because the speech tests are more sensitive to the underlying auditory deficits than non-speech tests (AAA, 2010). Consequently a greater proportion of speech tests within an AP test battery may potentially lead to a higher diagnosis of APD. Currently, the clinical standard of care provides no specific guidelines in the selection of the number of tests in the AP test battery and recommendations for the types of tests (speech/ non-speech). Consequently, the diagnostic criterion of APD remains an open topic for discussion and as a result, there is currently is no gold standard "test battery" for APD diagnosis. Recommendations for such an accepted standardized test battery need to address the diagnostic role of speech and non-speech tests in the assessment of central auditory processing.

Recently, it has been suggested that the inclusion of non-speech tests in diagnosis of APD may reduce the confounding influence of language on an individual's performance (Moore, 2006). Individuals with language impairment perform poorly on speech tests and perform well on non-speech tests (Moore, 2006); therefore, the use of non-speech tests would help to differentiate receptive language impairments from APD (McArthur, 2009).

Influence of language background on the speech based AP tests has been reported (Tebri, Charca, & Pring, 2011). It is observed that normal hearing bilinguals performed poorer on the second language compare to the monolingual native speaker for the same language in adverse listening condition (in noise), whereas their performance was same in quiet. (Crandell & Smaldino, 1996; Shi, 2009; Tabri et al., 2011). Tabri and colleague (2011) reported poor speech perception in noise in highly proficient second language users. Language background influences AP assessment results when speech stimuli with noise, degraded speech signal, or filtered speech are used. It is a challenge to include a speech-based test in the assessment for APD in multilingual population. To use speech based tests in assessment of APD in multilingual population, tests need to be developed in native languages, which is not a feasible choice considering the cost and the efforts (Lew & Cannon, 2010). Translating one test in to other languages may not be a good idea because different languages have different neurophysiological representation and therefore the translated test may not be assessing the same auditory process as standardized test (Valaki et al., 2004). Dawes and Bishop (2007) reported the performance of children in United Kingdom on SCAN-C is significantly worse than American children because of the deference in accent. Rerecording of this test in native accent also may not be the solution as each region has different accent.

There is no consensus on the use of speech stimuli in AP tests. Most of the diagnosed APD individuals show deficit on speech-based tests whereas normal performance on non-speech test. This leads to a question, whether this problem is related to processing of all auditory stimuli or is it specific for speech signal? (Moore, Rosen, Bamiou, Campbell, & Sirimanna, 2013). If the problem is related to speech only then it may involve phonetic level of linguistic processing. Poor performance on speech based tests are interpreted as problem in processing basic sounds by CANS, whereas there is possibility of problem in memory, attention or linguistic processes such as phonetics, syntax, semantics and vocabulary.

Tests such as competing sentence test in SCAN-C are used as a diagnostic test for APD. In this task, the individual has to listen two different sentences simultaneously and repeat the sentence from the specific ear and ignore the sentence in other ear. However, performance on sentence repetition task is also a diagnostic measure for language impairment (Conti-Ramsden, Botting, & Faragher, 2001). Children with language impairment perform poor on these tests because of linguistic deficit and not auditory. Results of other tests, such as filtered words, in which the individual has to recognize the word presented through low pass filter, influenced by the knowledge of vocabulary and hence could not be a valid measure of auditory processing (Loo, Bamiou, & Rosen, 2013).

There are differences in opinion among the researchers about the use of speech tests in diagnosis of APD, but current clinical guidelines (AAA, 2010; ASHA, 2005) do not provide any recommendations about the use of speech and non-speech tests in AP assessment and whether or not failure on non-speech test is required to diagnose APD. There is need to define the inclusion of number of speech and non-speech tests in a test battery and more specific diagnostic criteria.

AP Assessment Procedures

Tests selected to assess APD should demonstrate high sensitivity, specificity and efficiency (ASHA, 2005). There are many tests for APD diagnosis that are sensitive and well standardized, although their validity remains questionable (Dawes & Bishop, 2009). Procedure related skills that demand language, memory, attention and IQ can have significant effects on performance on AP tests (Dawes & Bishop, 2009). Some AP tests use linguistic material, such as sentences and require a child to repeat spoken sentences, a task which is shown to be a marker of language impairment (Conti-Ramsden et al.,2001).

A test of auditory processing also assesses non-sensory cognitive processing abilities. Tasks such as duration pattern sequence (participant has to listen to stimuli and respond according to the perceived duration of the stimuli, such as short-short-long or long-short-long), distinguishing the frequency pattern sequence (such as high-high-low or low-high-low) and dichotic digits (2 7, 5 3, 18) demand attention and memory processing. Moore et al. (2010) described the role of attention and working memory in the poor retest reliability of AP tests. Riccio et al. (1996) investigated the level of association between the staggered spondaic word (SSW) test, which is widely used for the diagnosis of APD (Musiek & Baran, 1987), and psychological measures such as inattention, impulsivity, hyperactivity and linguistic and cognitive abilities. The SSW test scores correlated most with cognitive ability, expressive language and auditory memory. Further, the symptoms of APD are closely related to attentional and working memory problems (Moore et al., 2010). However, the extent to which memory and attention contributes to performance on AP tests is not yet clear. Sharma et al. (2009) studied the nature of auditory processing difficulties among children with language and/or reading difficulties and also investigated the link between auditory processing, sustained attention and short-term memory. They reported that LI and reading disorder co-occur with APD and that attention and memory influences performance on some of the auditory tasks, but only explains a small amount of variance in scores.

The influence of language ability on a test performance can be minimized by using nonlinguistic stimuli to assess APD (Dawes & Bishop, 2009; McArthur, 2009). However, the influence of language abilities cannot be ruled out completely even by using non-word stimuli. It was found that prior linguistic knowledge can affect performance on such a test (Thorn & Gathercole, 1999). For children with language or learning difficulties even spatial relations such as high or low (during pitch pattern tests where three stimuli are presented and the individual has to respond high-low-high, or high-high-low) are difficult to perform and labeling of these stimuli also demand language-processing abilities (Bishop, 1997).

Schow and Chermak (1999) administered a common AP test battery on school age children that included SSW and a SCAN screening test for APD to address four key skills: dichotic processing, temporal processing, auditory closure and auditory foreground background differentiation. The authors reported a large amount of variance which could not be explained by these four auditory skills and raised a possibility of other factors (Schow & Chermak, 1999). On some APD measures such SCAN-C, the effect of working memory was assessed. It was found that when working memory was controlled there was no significant difference between children with language impairment and age matched controls on AP tests (Lum & Zarafa, 2010). This means that difficulties with the SCAN-C test indicates a problem with working memory that also applies to the other AP tests (Kamhi, 2011).

AP tests are relatively quick and can be affected by lapses in attention. Children with SLI need more time to respond and therefore it is possible that the group differences in SLI and controls are due to differences in reaction time (Rosen, 2003). It is important to consider factors such as task familiarity, working memory demands and response time while assessing children with SLI. Unfortunately, all non-speech as well as speech-based AP tests are influenced by cognitive involvement such as attention and memory. The ASHA (2005) technical report states that APD is not the deficit due to higher cognitive functions such as attention. This makes it difficult to diagnose an individual with poor attention on auditory processing tests. Task difficulty in AP assessment is an important factor that influences the results. Children with SLI are slow learners and perform poorly on the auditory processing tests because of the task learning difficulty (Marler et al., 2001). Marler et al. (2001) reported improvement in the performance of both groups (SLI and control) with successive trials on backward masking tasks, suggesting that backward masking tasks were partly dependent on the task familiarity.

Among the numerous concerns about the validity of AP testing is whether the current auditory processing tests measure the integrity of central auditory nervous system (CANS) or if they are instead sensitive to non-auditory factors. It is evident that children with ADHD, LD and SLI exhibit neural timing deficits and need a longer response time than age matched typically developing peers. The rapid nature of tests and complexity of auditory processing tasks makes these children at risk for getting diagnosed as APD. This serves to underscore the need to develop comprehensive assessment procedures to accommodate children with ADHD, LD and SLI by reducing the impact of higher order processing. The need to develop an improved method for assessment and diagnosis of APD is evident.

APD Diagnostic Criteria

To diagnose APD, audiologists perform a set of tests (test battery) that assesses various auditory processes, including auditory discrimination, temporal aspects of audition, localization and lateralization, auditory pattern recognition, auditory performance in competing acoustic stimuli and auditory performance with degraded acoustic signals (ASHA, 2005). There is freedom for audiologists to select a test battery based on the patient's referral complaint, age, motivation level and other cognitive linguistic factors.

The Central Test Battery (CTB) is one of the most widely used test batteries in the United States (US) to diagnose APD (Chermak et al., 1998; Schow & Chermak, 1999). The CTB, developed by Jack Katz (1992), consists of three widely used tests: Staggered Spondaic Word (SSW), Phonemic Synthesis Test (PST) and Speech in Noise (SN) test. The CTB uses different cutoff criteria for children and adults. The central auditory nervous system is not fully matured in young children; therefore below the age of 12, CTB uses age specific norms. For age 12 and above, performance on CTB becomes adult-like; therefore norms are the same from age 12 to 59. CTB recommends different cutoff points for children and adults to decide pass or fail status. It was reported that the SD of test scores for 7-year-old children was 11% compared to 4% for adults. Because children have relatively large SDs even within the same age group, the use of 2 SD below the mean as the cutoff criteria would cause too many APD children to not be diagnosed. Therefore, 1 SD below mean as the cutoff was recommended for children. However, for individuals above age 12, 2 SD below mean as the cutoff was recommended (Katz, 1992).

While the cutoff score recommended for children on AP tests by the AAA and ASHA guidelines is 2 SD below the mean, the CTB recommends 1 SD below the mean. It is evident that there is no uniformity about using cutoff scores among clinicians across the country. The discrepancy in the use of cutoff scores as recommended by AAA, ASHA and CTB leads to different failure rates on AP tests and the rate of APD diagnosis. There are concerns about the selection of tests for AP test battery, assessment procedures and use of different cutoff points to diagnose APD. Impact of these factors has not been reported before on failure rate of AP tests and APD diagnostic rate.

Study 1: The purpose of this study was to quantify the failure rate of AP tests (speech and non-speech) and to measure the APD diagnosis rate using four different diagnostic criteria in a large sample of participants assessed for APD.

Study 2: This study determined the effect of varying response time on the performance of children with LD on AP tests. This study also considered whether practice affected test performance.

Study 3: The purpose of this study was to determine whether or not the current sample of participants assessed for AP was normally distributed between 1 SD and 2 SD below mean. The study measured the differences in test failure rate and APD diagnostic rate for children using two different cutoff criteria: 1 SD below mean, as recommended by Central Test Battery (CTB) and 2 SD below mean, as recommended by ASHA (2005).

CHAPTER III

APD DIAGNOSTIC RATE CHANGES WITH DIFFERENT DIAGNOSTIC CRITERIA BASED ON INCLUSION OF SPEECH AND NON-SPEECH TESTS

Abstract

Purpose: The purpose of this study was to quantify the failure rate of AP tests (speech and non-speech) and to measure the APD diagnosis rate using four different diagnostic criteria in a large sample of participants previously assessed for APD.

Methods: Data were collected retrospectively from the medical record review of 117 participants (Male = 64, Female = 53) between the ages of 7.1 and 57.0 years. The AP test battery consists of up to six tests, three speech and three non-speech tests. Not all participants completed all tests due to individual factors, such as age. Failure rates of speech and non-speech tests were measured. Each participant was classified as having or not having APD based on four different diagnostic criteria derived from the published ASHA, AAA and BSA guidelines.

Results: The failure rate for AP tests varied from 14.3% to 76%. Overall the failure rate of non-speech tests was lower than speech tests. The APD diagnosis rate based on four diagnostic criteria ranged from 9.52% with strict criteria to 68.37% with lenient criteria.

Conclusions: The AAA and ASHA guidelines need to develop more specific recommendations regarding the need and value of inclusion of non-speech tests in AP assessment to avoid variation in the diagnostic rate.

Auditory processing disorder (APD) is a deficit in neural processing of auditory stimuli in the central auditory nervous system (CANS) and a comorbid condition with various developmental disorders including language impairment (ASHA, 2005). The failure on two or more tests from an auditory processing (AP) test battery is a requirement to diagnose an individual as APD. AP tests are based on speech as well as non-speech stimuli. In the AP assessment battery, each test has a different failure rate. The APD diagnostic rate varies depending on which test is selected from the AP test battery (Musiek, Geurkink, & Kietel, 1982; Wilson & Arnott, 2013). Among individuals with APD, failure rate is higher on speech tests compared to non-speech tests (Wilson & Arnott, 2013), because the speech tests are more sensitive to the underlying auditory deficits than the non-speech tests (AAA, 2010). A greater number of speech tests in an AP test battery may potentially lead to a higher APD diagnosis rate. There are no standards regarding the number of tests to be administered and the types of tests (speech/ non-speech) to be included in an AP test battery. Therefore, the diagnostic criteria for APD remain an open topic for discussion and, there is currently no gold standard "test battery" for APD diagnosis.

Guidelines given by the American Speech-Language-Hearing Association (ASHA, 2005) and the American Academy of Audiology (AAA, 2010) are widely used for the assessment and diagnosis of APD. AAA (2010) and ASHA (2005) provide specific guidelines about assessment procedures and diagnostic criteria, but offer flexible guidelines for test battery selection that gives freedom to clinicians to select an individualized AP test battery. Clinicians use different test batteries to assess and diagnose APD. Factors that influence the test battery include age of the patient, medical history, referring complaint, task complexity, maturational variability, response demand for the task and individual attributes such as language development, motivational level, fatigability and attention.

The list of recommended AP tests provided by AAA and ASHA include speech as well as non-speech tests. There is no consensus among professional groups about whether failure on a non-speech test should be required to diagnose APD. AAA and ASHA guidelines do not make any recommendations about the inclusion of non-speech tests in the AP test battery or whether failure on a non-speech test is required to diagnose APD. In contrast, the British Society of Audiology (BSA) guidelines clearly state that, to diagnose an individual as APD, the individual should fail at least one non-speech test (BSA, 2011). The BSA guideline further states that difficulty in perceiving speech may also result from other causes such as language impairment. Therefore, failure on speech tests alone is not sufficient to diagnose an individual as APD.

APD affects processing of both speech and non-speech signals. It is reported that speech stimuli are processed differently than non-speech stimuli (Dawes & Bishop, 2009; Mody, Studdert-Kennedy, & Brady, 1997). The AAA clinical guideline also suggests that the speech stimuli provide access to different processes as compared to non-speech stimuli (AAA, 2010); this suggests that there is a possibility of an individual having difficulty in processing speech stimuli only and can adequately process non-speech stimuli. Additionally, speech-based tests may have language confounds that will increase the probability of children with language disorders failing the AP assessment (Moore, 2006; Ferguson et al., 2011). Influence of language background on AP test results was reported when speech stimuli with noise, degraded speech signals or filtered speech were used (Crandell & Smaldino, 1996; Shi, 2009; Tabri, Charca, & Pring, 2011). The inclusion of non-speech tests in an AP assessment battery can help differentiate language impairment from APD (McArthur, 2009) because children with language impairments often perform better on non-speech tests than speech tests (Moore, 2006).

AP tests are designed to tax the auditory system, but at the same time it also increases non-auditory demands such as language processing, attention and motor response. AP tests with more attentional, linguistic or motor demands have higher failure rate compared to tests with less demands (Wilson & Arnott, 2013). Additionally, compared to non-speech tests, speech tests add more linguistic demands. Different failure rate for the speech and non-speech AP tests among individuals assessed for AP were previously reported (Sharma, Purdy, & Kelly, 2009; Wilson & Arnott, 2013).

AP tests such as Pitch Pattern Sequence (PPS), Random Gap Detection (RGD), Duration Pattern Sequence (DPS), Staggered Spondaic Word (SSW), Competing Sentence (CS) and Phonemic Synthesis (PS) were among the most widely used tests in clinic to diagnose APD. The first three tests are based on non-speech stimuli and the other three tests use speech stimuli. The failure rate for non-speech tests such as PPS – 12% (Wilson & Arnott, 2013), 25% (Sharma et al., 2009), 10% (Jutras et al., 2007); and for RGD– 25% (Sharma et al., 2009) were reported. The failure rate for speech tests such as SSW (failed anyway) – 80% (Jutras et al., 2007); and CS - 86.4% (Musiek et al., 1982), 77.3% (Wilson & Arnott, 2013) were reported. It is evident that the test failure rate is higher for the speech tests than non-speech tests. The test battery used to diagnose APD often consists of speech-based tests. That creates a possibility of over-diagnosing APD among the language-impaired population.

Not surprisingly, different models of APD result in different diagnosis rates (Jutras et al., 2007). Based on AP test results, language status and academic difficulties, two models (Bellis/Ferre model and Buffalo model) were proposed to classify children assessed for APD. These models were derived to guide clinicians for diagnosis and intervention of APD. Buffalo model depends mainly on SSW test results (speech test) whereas Bellis/Ferre model uses a broader approach that include both speech and non-speech tests. In a retrospective study Jutras et al. (2007) classified 178 children who were assessed for AP, using Bellis/Ferre model and Buffalo Model. The authors found that, the diagnostic rate for APD was around 8% when using Bellis/Ferre model compared to 80% using the Buffalo model. This supports the notion that diagnostic rate for APD changes with the types of test included in a test battery.

Similarly, Wilson and Arnott (2013) retrospectively analyzed records of 150 children and classified them with 9 diagnostic criteria. The nine criteria were based on the current positions of three professional groups (AAA, 2010; ASHA, 2004; BSA 2011). They classify children based on: failure on one test /two tests; failure on speech test /non-speech test; and failure in one ear / both ear. The authors found the APD diagnostic rate changes from 24.7% for the strict criteria (i.e. Failed ≥ 2 tests binaurally, with at least 2 non-speech tests) to 71.3% for the lenient criteria (i.e. Failed ≥ any 2 tests monaurally). Their findings clearly indicate that the diagnosis rate decreased when failure on non-speech tests were added to diagnose APD. They have used monaural and binaural failure requirements to diagnose APD whereas none of the position statement recommends using test failure in both ear is required, therefore the current study used monaural failure on AP tests as a failure on the test. The AAA (2010) clinical guideline clearly states that the client has to fail at least monaurally. In the present study, all the test results were classified pass/fail based on the auditory deficit in at least one ear. If an individual failed on AP test at least monaurally, then it was counted as the person having failed that test. Information regarding monaural vs. binaural differences will not be reported in this manuscript, but will be reported in a separate data analysis and publication.

In previous studies by Jutras et al. (2007) and Wilson and Arnott (2013), did not include a broad age range (adults) and most of the tests used were monaural tasks. Additionally these studies did not measure the difference in the failure rate of speech and non-speech tests in a long AP test battery. In the present study, differences in failure rate of speech and non-speech AP tests in a broad age range were measured. The current study also compared diagnostic rate using four different criteria to diagnoses APD. These four APD diagnostic criteria were based on the current position statement and clinical guidelines by three professional groups (AAA, ASHA, and BSA) and researchers who recommend the use of only non-speech tests for the diagnosis of APD (Dawes & Bishop, 2009; McArthur, 2009).

Four criteria derived based on the three clinical guidelines for the assessment and diagnosis of APD are:

1. Failed two or more speech and or non-speech tests (AAA, 2010; ASHA, 2005)
2. Failed two or more speech tests (AAA, 2010; ASHA, 2005)
3. Failed two or more tests with at least one speech test and at least one non-speech test (BSA, 2011)
4. Failed two or more non-speech tests (Dawes & Bishop, 2009; McArthur, 2009)

Method

Participants

AP test result data were extracted from 117 patient files (64 males and 53 females) from a computer database of patients assessed for APD at the University of North Carolina at Greensboro (UNCG) Speech and Hearing Center. Permission was obtained from the UNCG Institutional Review Board (IRB) to access patient files for the purposes of research. Patients referred to the UNCG Speech and Hearing Center for AP evaluation between August 2003 and September 2011 had the results of their medical history and AP test results stored in a de-identified database. Participants assessed for AP ranged in age between 7.1 and 57.0 years, with a median age of 12.7 years (first quartile = 10, third quartile = 17).

For inclusion in the present study, the following criteria were met for all participants: (a) user of English as their first language (reported by self or parents/guardians); (b) normal hearing sensitivity (hearing thresholds below 25 dB HL, tested for frequencies between 250-8000 Hz); (c) normal middle ear function and tympanograms with a static compliance ≥ 0.2 ml and tympanic peak pressure between -100 and +50 daPa as per Jerger (1970); (d) had no history of neurological disorder; (e) completed at least three behavioral AP tests, at least one of which was a non-speech test. Audiometric and AP tests were performed in a sound treated booth on calibrated audiometric equipment.

AP Test Battery

All standardized AP tests were presented from recorded CD's. These assessments were conducted and/or supervised by licensed audiologists. The UNCG AP test battery includes six tests based on recommendations of ASHA (2005), AAA (2010), Katz (1992), and Bellis (2003). Test selections were individualized for each patient and were selected based on the presenting complaints, reported individual listening difficulties and the age of the participant. Thus, not all participants were assessed with all six tests. AP test battery used for assessments is reported in Table 1.1.

Data Collection and Analysis

The raw scores for the PPS, RGD, DPS, DD, SSW and CS tests from the AP test battery were collected from participant files and entered into a SPSS datasheet. These scores were then compared to the age norm (2 SD below the mean) to classify them as pass or fail on that particular test. Scores that were at least 2 SDs below mean were considered as failures. If an individual failed AP test on one ear, it was counted as a failure. The pass or fail results were then analyzed using four diagnostic criteria described previously. Participants who failed at least two tests were classified as APD.

Table 1.1. Description of AP Tests; Speech and Non-speech

AP test	Protocol
Non-Speech Tests	
Pitch Pattern Sequence Test (PPS)	Level: 50 dB SL in both ears; Scoring: Count the number of correct responses
Random Gap Detection Test (RGD)	Level: 50 dB SL in both ears Scoring: Measure the smallest gap an individual can detect
Duration Pattern Sequence Test (DPS)	Level: 50 dB SL in both ears Scoring: Count the number of correct responses and compare with the norms
Speech Tests	
Staggered Spondaic Word Test (SSW)	Level: 50 dB SL in both ears Scoring: Count numbers of errors for each test item; mark qualifiers
Competing Sentences Test (CS)	Level: 35 dB SL to the test ear and 50 dB SL to the non-test ear Scoring: Score on a 10-point scale. Deduct 2.5 for each quarter of the sentence missed
Phonemic Synthesis Test (PS)	Level: 50 dB SL in both ears Scoring: Count the number of correct responses

Results

Failure rates on speech and non-speech AP tests were measured. Table 1.2 shows the descriptive statistics about the participants' performance on each test, with tests being grouped into "non-speech tests" and "speech tests." The number of participants tested on each test and number of participants failed on each test were compared. Percentage scores were calculated to determine the failure rate. Each AP test had a different failure rate. The failure rate was lowest for the non-speech RGD test (14.3%) and highest for the speech CS test (76%). An overall comparison showed that all the non-speech tests (PPS, RGD and DPS) had a lower failure rate compared to the speech tests (PPS, SSW and CST). Thus, non-speech tests were abnormal in approximately one-third of patients referred for an AP evaluation, whereas between one half to three-quarters of suspected APD patients failed AP speech tests.

Table 1.3 shows the percentage of participants who failed speech and non-speech tests. Three conditions were measured: 1) did not fail any test (14.52%); 2) failed at least one non-speech test (31.62%); and 3) failed at least one speech test (84.61%). The failure rate for speech tests was much higher than the failure rate of non-speech tests. Again, less than one third of patients suspected of having APD failed the non-speech tests.

Table 1.2. Number of Participants who were Tested and Number of Participants Failed for Non-Speech Tests and Speech Tests

Test Name	(N=117)	
	Number of Participants Tested	Number of Participants Failed (%)
	Non-Speech Tests	
RGD	42	6 (14.3%)
PPS	23	5 (21.7%)
DPS	94	33 (35.1%)
	Speech Tests	
PS	115	52 (45.2%)
SSW	116	80 (69%)
CS	100	76 (76%)

Table 1.3. Test Failed: Speech vs. Non-Speech

Failure Criteria	(N=117)
Not Failed any test	17 (14.52%)
Failed at least one non-speech test	37 (31.62%)
Failed at least one speech test	99 (84.61%)

Table 1.4 shows the number and percentage of participants diagnosed as having APD using each of the four diagnostic criteria. The lowest diagnostic rate for APD (9.5%) was observed for the stringent criterion (i.e. failure on at least two non-speech tests). The highest diagnostic rate for APD (68.3%) was observed for a lenient criterion (i.e. failure on any two tests). The APD diagnosis rate decreases as non-speech test failure were added to the diagnostic criteria. Thus, the inclusion of a non-speech test within an AP test battery can decrease failure rate and decrease the diagnosis of APD.

Table 1.4. Diagnostic Rate Using Four Different Diagnostic Criteria

Criteria	Percentage Diagnosed as APD
Failed any two tests (N=117)	80 (68.37%)
Failed two speech tests (N=117)	75 (64.1%)
Failed one speech and one non-speech test (N=117)	36 (30.71%)
Failed two non-speech tests (N=42)	4 (9.52%)

Note: Percentages were calculated based on the number individual tested for each of the 4 conditions and not for the whole sample of 117 participants. 2 or more non-speech tests were administered in 42 participants.

Table 1.5, column 1 shows the number of AP tests failed (test battery includes both speech and non-speech AP tests). Columns 2 indicate the percentage of participants who failed on speech tests only. The table indicates that if an individual fails two tests then there is very high probability that the tests were speech-based tests only (around

85%). In other words, when failed 2 tests approximately 15% of participants failed on at least one non-speech tests. Because the number of test administered vary from at least three to maximum five tests in the sample of participants assessed for AP, a subset (42 participants) of sample was analyzed to reconfirm the findings about the failure rate of speech tests and non-speech tests. A subset consists of 42 participants who were assessed for four AP tests with two speech and two non-speech tests, were analyzed separately. The results were consistent with speech tests having higher failure rate than the non-speech tests (Table 1.6 & 1.7). The results were even with the four diagnostic criteria (Table 1.8).

Table 1.5. Percentage of Speech Tests Only Failed in AP Test Batteries

Number of Tests Failed	Percentage Failed Speech Tests Only (%)
1	95% (19/20)
2	84.8 % (28/33)
3	57.1% (16/28)

Table 1.6. Number of Participants who were Tested and Number of Participants Failed for Non-Speech Tests and Speech Tests in a Subgroup of 42 Participants

Test Name	(N=42)	
	Number of Participants Tested	Number of Participants Failed (%)
	Non-Speech Tests	
RGD	42	6 (14.28%)
DPS	42	15 (35.71%)
	Speech Tests	
SSW	42	24 (57.14%)
CS	42	32 (76.19%)

Table 1.7. Test Failed: Speech vs. Non-Speech in a Subgroup

Failure Criteria	(N=42)
Not failed any test	7 (16.66%)
Failed at least one non-speech test	17 (40.47%)
Failed at least one speech test	35 (83.33%)

Table 1.8. Diagnostic Rate Using Four Different Diagnostic Criteria in a Subgroup

Criteria	Percentage Diagnosed as APD (N = 42)
Failed any two tests	30 (71.42%)
Failed two speech tests	28 (66.66%)
Failed one speech and one non-speech test	17 (40.47%)
Failed two non-speech tests	4 (9.52%)

Discussion

The purpose of this study was to quantify the failure rate of AP tests (speech and non-speech) and to measure the APD diagnosis rate using four different diagnostic criteria in a large sample of participants assessed for APD.

As expected based on previous research (Wilson et al., 2013. Moore, 2006), non-speech tests (PPS, RGD and DPS) had a lower failure rate than speech tests (SSW, CS and PS). The results of this study are consistent with the findings of Wilson et al. (2013) that fewer participants fail non-speech tests and also about how the diagnostic rate changes with using different diagnostic criteria. Although Wilson et al. (2013) included monaural vs. binaural failure as a criterion to classify participants for APD, none of the three professional groups state the individual has to fail binaurally. Thus, this criterion was not used in the present study. Failure rate using the four criteria were, failed any two tests (68.3%), failed two speech tests (64.1%), failed one speech and one non-speech test (30.7%) and failed two non-speech tests (9.5%). With addition of non-speech test, APD diagnostic rate decreased. It indicates that including more speech tests increases the APD diagnosis rate and including more non-speech tests decreases diagnosis rate.

It is an important issue to note that very few participants (31.6%) failed at least one non-speech test. There could be three reasons for the less failure on non-speech tests:

a) Participants mainly have difficulty with processing speech;

b) Few participants had deficit in temporal processing;

c) Non-speech tests are not sensitive to milder forms of APD.

APD and Speech Processing

Difficulty in processing speech sounds could also be due to language impairment or non-native experience of language (BSA, 2011). Language background influenced AP assessment results when speech stimuli with noise, degraded speech signals or filtered speech were used (Crandell & Smaldino, 1996; Shi, 2009; Tabri et al., 2011). Speech based tests are not specific to differentially diagnose between APD and other language-related disorders such as Specific Language Impairment (Ferguson et al., 2011). Children with other language impairment perform poorly on only speech-based AP tests; hence, recent position statement from BSA has questioned the diagnosis of APD with using speech tests only. The ASHA guidelines state that APD is a disorder of "neural processing of auditory stimuli that is not due to higher-order language, cognitive, or related factors" (ASHA, 2005). This current standard of practice could thus be interpreted as recommending that AP testing should include non-speech tests. On the other hand the American Academy of Audiology (2010) clinical guidelines explicitly states that, "speech tasks remain an important component of the AP test battery, as CANS deficits are often apparent for speech (versus non-speech) signals in children and adults on both psychophysical and electrophysiologic measures. Speech signals provide access to different processes in CANS which are more vulnerable to disruption (AAA, 2010)." It is clear from the recommendations of three clinical guidelines (AAA, ASHA, and ABA) that the AP diagnosis should be done based on failure of speech and non-speech tests.

Temporal Processing Deficit

Most participants diagnosed with APD show a deficit on speech-based tests but normal performance on non-speech tests. The findings of the current investigation are consistent with the previous findings that fewer participants fail on non-speech tests compared to speech tests (AAA, 2010; Wilson et al., 2013). The findings indicate that fewer participants showed a deficit in temporal processing. Non-speech tests utilized in this study assess auditory patterning and temporal processing. It is possible that the prevalence of deficit in these two auditory processes is lower than binaural integration (SSW) and binaural separation (CS) auditory processes.

Sensitivity of Non-Speech Tests

It was found that the participants failed non-speech test when they failed approximately more than three tests. The findings of this study suggest that non-speech tests are abnormal in more severe cases of AP (abnormal in participants who failed more than 3 tests).

Importance of Non-Speech Tests

1. Non-speech tests provide access to the different auditory processes than speech tests and therefore provide more complete assessment of CANS.
2. Failure on non-speech tests is an indicator of the severe case of APD and provides more conservative approach of APD diagnosis and gives confidence to the clinician to reduce the false positive diagnosis of APD.
3. Non-speech tests are useful in assessing participants whose primary language is not English.

Factors Contributing to the Failure Rate (Table 1.9)

1. *Auditory processes:* Each test included in the test battery assesses different auditory process. Higher failure on SSW and CS tests indicate that children with APD have difficulty prominently in processing dichotic speech and could be addressed to the poor functioning of corpus callosum and inter-hemispheric neural tracts.
2. *Language demands:* Failure rate was lower for the tests with lower linguistic demands (non-speech tests). Within speech tests CS has highest linguistic demands as it uses sentences compared to SSW uses four words. PS uses sound blending to form a word, failure rate for CS (76%) & SSW (69%) was higher than PS (45.2%).
3. *Attentional demands:* All AP tests required sustained attention to perform throughout the test. Only SSW and CS require divided and selective attention respectively. Tests with more attentional demands (SSW & CS) had higher failure rate than tests with lower attentional demands (PPS, DPS, RGD and PS).
4. *Response length:* In all AP tests the participants hear the stimuli and respond verbally. The response length varies among the tests from one word (RGD, PS) to more than four words (CS). Higher failure rate was observed for the tests with longer response lengths (CS and SSW).
5. *Response time:* Shorter response time adds additional memory and attentional demands. In this study, participants were given enough time to respond and tests were administered with adequate pauses when required.

Table 1.9. Potential Factors that Contribute to the Failure on AP Tests

Tests	Auditory Process	Linguistic Component	Attentional Factor	Response Length
PPS	Auditory pattern recognition	-	Sustained attention	3 words
RGD	Auditory temporal processing	-	Sustained attention	1 word
DPS	Auditory pattern recognition	-	Sustained attention	3 words
SSW	Binaural integration	Words	Divided and sustained attention	4 words
CS	Binaural separation	Sentences	Selective and sustained attention	More than 4 words
PS	Phonemic blending	Sound blending	Sustained attention	1 word

Recommendations for AP Test Battery

From the results of this study following recommendations were suggested to the hearing health care professionals for developing a general guidelines for AP test battery:

1. Test battery of AP should include at least three AP tests with at least one non-speech test.
2. If the length of the test battery is an even number (4/6), then an equal number of speech and non-speech tests should be included.
3. Failure on one speech and one non-speech test should be required to diagnose APD.
4. If clinicians want to use more conservative or stringent approach, then failure on two non-speech tests can be used as criteria to diagnose APD.
5. If clinicians want to use less stringent approach, then failure on any two (speech/ non-speech) tests can be used as criteria to diagnose APD.
6. Whether clinicians use stringent or non-stringent criteria, the question about the diagnostic rate of APD remains debatable. It is recommended that the current clinical guideline should provide detailed recommendations about use of speech and non-speech tests in APD diagnosis to bring uniformity among clinicians.

Results of the current investigation do not support the recommendation of using only non-speech tests in AP assessment. The professional guidelines need to be revised. Given the differences in the failure rate on speech and non-speech tests professional guidelines should suggest a number of speech and non-speech tests available that could be utilized in an AP test battery.

Future Research

Future research needs to determine the proportion to which corpus callosum functioning contributes in the failure of dichotic speech tests. The failure rate on non-speech tests, which assess auditory processes other than temporal processing, needs to be determined. Tests of binaural interaction (masking level difference, localization, lateralization) and auditory discrimination (difference limens for frequency and psychophysical tuning curves) can be used to determine whether the low failure rate on non-speech tests is due to lower occurrence of temporal processing deficit among children with APD.

CHAPTER IV

EFFECT OF VARYING RESPONSE TIME AND PRACTICE ON MEASURES OF AUDITORY PROCESSING

Abstract

Purpose: Children with learning disabilities have slower response time and often perform below the level of typically developing peers on auditory processing measures. This study determined the effect of varying response time on the performance of children with LD/RD on AP tests. This study also considered whether practice affected test performance.

Method: 24 children with learning disabilities (LD) and 12 typically developing (TD) age peers participated in this study. Age ranged from 9-13 years (M = 10.82, SD = 1.26). Participants were administered three AP tests, dichotic digit, duration pattern sequence and random gap detection, in two conditions: standard response time and extended response time. Practice was examined by computing difference in scores on 1st half compared to 2nd half of the test.

Results: As expected the TD groups performed significantly better on the three AP tests than the LD group. With extended time, the LD group significantly improved their performance on the DD test whereas the TD group showed no change in performance. Both groups performed similarly on the first and second parts of the tests, thus showing no benefit from practice.

Conclusion: The findings of this study suggest that longer response time should be provided to LD children while assessing on AP test. Longer response time could reduce the higher cognitive, linguistic confounds in AP assessment.

Key Words: Auditory processing, assessment, response time

Children with learning disabilities (LD) often get diagnosed with auditory processing disorder (APD) (Fostick, Bar-El, & Ram-Tsur, 2012; Iliadou, Bamiou, Kaprinis, Kandylis, & Kaprinis, 2009; Sharma, Purdy, & Kelly, 2009). Compared to their typically developing peers children with LD or reading disorder (RD) perform poorly on auditory tasks: auditory discrimination, auditory temporal processing, auditory pattern recognition and auditory performance in competing acoustic signals (Sharma et al., 2009; Tallal & Stark, 1981). The nature of this processing deficit is not completely understood and is still a matter of debate (Klein & Farmer, 1995; Studdert-Kennedy & Mody, 1995; Tallal, 1984).

The initial work of Tallal & Piercy (1973, 1981) and Haggerty & Stamm (1978) reported that, compared to controls, LD children require longer inter stimulus intervals (ISI) to discriminate two different stimuli in an auditory task. Tallal’s (1980) work was one of the first to provide an explanation for the connection between impaired auditory processing (temporal processing) and phonological processes in word identification. In addition to auditory tasks LD children performed poorly on rapid visual tasks that suggests the problem is not specific to auditory input (Elliott, Hammer, & Scholl, 1989). Previous research has reported various non-phonological deficits among children with dyslexia, such as reduced speed in information processing (Denckla & Rudel, 1976;

Nicolson, 1994), problems in visual processing (Stein, 1989), and problems in motor skills (Rudel, 1985). The nature of this deficit is much broader and extends beyond the auditory modality and auditory processing could be a part of this broader deficit (Kamhi, 2011).

There is no general agreement among researchers on whether or not children with LD have APD (Ferguson, Hall, Riley, & Moore, 2011; Fey et al., 2011; Kamhi, 2011; Rosen, 2005). There are numerous studies that have reported poor auditory processing (AP) abilities among LD children using AP tests (Iliadou et al., 2009; Sharma et al., 2009; Zaidan & Baran, 2013; King, Lombardino, Crandell, & Leonard, 2003). Others have questioned whether children with reading disorders or LD have APD (Rosen, 2003). However, there is agreement among researchers that children with learning disabilities have deficits in a range of temporal processing tasks (neural timing deficit) when they have to process rapidly presented stimuli. These temporal deficits were not restricted to auditory modality.

A number of auditory processing tests have been used successfully in identifying APD in children with LD (Bornstein & Musiek, 1992; Ferre & Wilber, 1986; Jerger, Martin, & Jerger, 1987). AP tests are designed in a way that challenges the processing of acoustic stimuli in the auditory nervous system by manipulating signal properties and presentation methods (loudness, pitch, duration, ISI, monaural, dichotic, competing, etc.). The American Speech and Hearing Association (ASHA, 2005) recommended a standardized test battery for AP assessment that includes various subjective and objective tests that measure the functioning of a wide variety of auditory processes (Schow, Seikel, Chermak, & Berent, 2000). To diagnose an individual as APD, it is required that the individual should fail (scores below two standard deviations) at least two tests or should fail (scores below three standard deviations) at least one test. During AP assessment, the audiologist should consider the attributes of the individual, such as language development, motivation level, attention, fatigue, mental age, native language, socioeconomic factors, and cultural factors. The test duration should be appropriate to the person's attention, motivation and energy levels (ASHA, 2005).

There are many AP tests, which are sensitive and well standardized, but their validity remains questionable (Dawes & Bishop, 2009). A valid test is one that measures accurately what it purports to measure. In the field of AP, it is presumed that AP tests measure central auditory dysfunction. However, it has been reported that AP tests are sensitive to measures of attention (Cook et al., 1993; Gascon, Johnson, & Burd, 1986), working memory (Lum & Zarafa, 2010; Riccio, Hynd, Cohen, & Molt, 1996), and learning abilities (Gomez & Condon, 1999). This might be the reason for high comorbidity of APD with attention deficit hyperactivity disorder (ADHD), LD and language impairment (LI) (Riccio et al., 1994; Yalcinkaya, Muluk, & Sahin, 2009).

The length of the stimulus and the task complexity varies among AP tests. On the standardized behavioral AP tests recommended by ASHA, the participant has to hear a set of speech or non-speech stimuli. Each test has several stimuli. Each stimulus of the test has an equal number of response items, but the number of response items varies from test to test. For example, the Dichotic Digit (two digit) test has four response items (eg., 2,5,8,4) while the Random Gap Detection test has one response item (eg., one or two).

Throughout the test, the participant has to consistently respond verbally to the auditory stimuli. Performance on AP tests varies with task complexity and practice. Most of AP tests are rapid in nature with short response times and the test scores can be affected by lapses in attention (Schwartz, 20011). Test stimuli with more items and shorter response times add additional working memory and motor demands. Furthermore, improvement in performance on a backward masking task was reported with practice (Marler et al., 2001). Children with LD need more practice to get familiar with the task (Smith & Strick, 1999). Considering the variation in practice required, memory and motor demands for an AP test, performance differs among participants on each test. However, the extent to which working memory and motor demands contributes to performance on AP tests is not yet clear. Sharma et al. (2009) studied the nature of auditory processing deficit among children with language and/or reading difficulties, and also investigated the link between auditory processing, sustained attention and short-term memory. They reported that LI and reading disorder (RD) co-occur with APD; attention and memory influences the performance on some of the auditory tasks but only explains a small amount of variance in scores.

Some children with LD fail on AP testing because of the non-auditory factors (task complexity, rapid presentation of stimuli, and high attentional and working memory demands) and not because of the deficit in the neural processing of the auditory stimuli (Coady, Kluender, & Evans, 2005; Marler et al., 2001; Schwartz, 2011).

The possible non-auditory factors contribute for the poor performances on AP tests:

1. Motor Deficit: Dyslexic adolescents and adults had difficulty pacing their responses with the external timing signal, i.e. metronome, and they failed to repeat the syllables correctly and hence, made more errors compared to the normal group (Wolff, Michel, & Ovrut, 1990). Another study reported a rate dependent motor deficit among individuals with dyslexia (Wolff, Michel, Ovrut, & Drake, 1990).
2. Language Deficit: Dyslexic children performed more poorly on time bound tests (Ellis & Miles, 1981; Seymour, 1986). Further more children with dyslexia have a deficit in access to the spoken word, which was discovered using the "rapid automatized naming" test (Denckla & Rudel, 1976). The rapid naming deficit was consistently replicated for auditory, visual and tactile (palpated) stimuli (Rudel, Denckla, & Broman, 1981; Swanson, 1987). It is evident that children with dyslexia will show a deficit on any task that demands continuous access to spoken language or verbal responses. This reduced speed of information could be attributed to impaired linguistic processing or some more global processing such as working memory or a motor timing deficit (Wolff, Cohen, & Drake, 1984).
3. Sluggish Attentional Shift: Sluggish attention shift was reported in dyslexic children which could impair the processing of rapid stimulus sequence in all sensory modalities; motor sequencing, and can also distort cortical feature representation (Hari & Renvall, 2001).

4. Slow reaction time: LD children have slower response time as compared to typically developing children (McGrady & Olson, 1970; Nicolson, 1994). The decision process or thought process is lengthier for children with LD.
5. Poor automaticity: Poor automatized processes measured using rapid word retrieval were reported in children with LD (Wolf, 1986). Denckla and Rudel (1974, 1976) concluded that among dyslexic children poor automaticity in lower level sub-processes is common for naming and reading. They also state that due to this difficulty to access name, attention cannot be allocated for higher-level comprehension processes. Poor automaticity and role of cerebellar impairment in individuals with dyslexia was reported (Nicolson, Fawcett, & Dean, 2001).
6. Rapid presentation: Tallal and Piercy (1973, 1981) reported that children with LD need longer ISI to discriminate two different tones. The deficit was also observed in visual and tactile modality.
7. Attention and working memory demands: Poor working memory abilities were reported in children with LD/RD (Daneman & Carpenter, 1980; McLean & Hitch, 1999; Swanson, 1993). AP tests are complex and sensitive to measures of working memory abilities. When controlled for verbal working memory demands children improved their performance on AP tasks (Lum & Zarafa, 2010).

Children with LD exhibit a neural timing deficit and need a longer response time than age matched typically developing peers on naming tasks (German, 1979). It was also reported that LD children could process better with slower rated speech tests (McCroskey & Thompson, 1973). Slower presentation rate facilitates real time auditory processing (Montgomery, 2004). Adding extra response time improved sentence comprehension among the LD children.

The rapid nature of auditory processing tests coupled with the linguistic demands of many AP tests increases the likelihood of children failing at least two tests and being diagnosed with APD. ASHA's (2005) guidelines emphasize that APD is a deficit in processing auditory stimuli (modality specific) and is not due to higher order language, cognitive or related factors. Therefore AP tests need to be administered in a way that minimizes the influence of these higher order cognitive functions. This serves to underscore the need to develop comprehensive assessment procedures to accommodate children with LD by reducing confounds of higher order processing. There is a need to modify AP assessment procedures for children with LD in order to differentiate children who actually have difficulty processing auditory information from those whose processing difficulty is the result of increased attentional, memory, and linguistic demands of the tests.

The purpose of the current study was to investigate the effect of varying response time on the performance of children with LD/RD on AP tests. This study also questioned whether children would perform better on the second half of AP tests than the first half. There is some evidence in the literature that children do better on AP tasks in subsequent administrations of the tests. It was reported that children with dyslexia performed better with practice on intensity and frequency discrimination, gap detection and time order judgment tasks (Schaffler, Sonntag, Hartnegg, & Fischer, 2004). Marler et al. (2001) reported improvement in scores among children with practice on backward masking tasks. Change in performance with practice in both studies has been measured overtime in multiple sessions.

Method

Participants

Two groups of children participated in this study. The first group was composed of 24 (M = 18, F=6) children previously diagnosed with learning disabilities, who ranged in age from 9;1 to 13;0 years (median age = 10.7 years, first quartile = 9.65, third quartile = 12.00). 13 children had a diagnosis of dyslexia without ADHD; 8 were diagnosed with both dyslexia and ADHD. The remaining 3 children showed significant learning problems but were not diagnosed with either dyslexia or ADHD. The second group consisted of 12 (M=7, F=5) typically developing children between the ages of 9;4 and 12;7 (median age = 10.65 years, first quartile = 9.70, third quartile = 11.77). All children showed normal hearing sensitivity and could follow the instructions for AP tests. Children who participated in this study were from Mumbai India. The testing was done at the Dhwani Early Intervention Centre (Mumbai). Approval from the Institutional Review Board at the University of North Carolina at Greensboro was obtained. Permission to conduct the research was also obtained from the center authorities.

Written consent was obtained from the parents as well as children participating in the study following a full explanation of the investigation being conducted. Participants in this age range were selected because at this age children have the required cognitive skills to perform auditory processing tasks. This avoids potential problems with the age-appropriateness of the test stimulus and task demands (Lovrich et al., 1996; Tallal, 2004; Walker et al., 2006).

Inclusion criteria for participant selection were as follows. Each participant had to have/or demonstrate:

a) Normal otoscopic examination and normal middle ear function (Type A tympanogram with a peak middle ear pressure between -99 and +50 daPa);
b) Normal hearing sensitivity (hearing thresholds 25 dB HL or better, tested for frequencies between 250-8000 Hz);
c) No medical history of behavioral, emotional, or neurological problems;
d) Normal intelligence level as assessed by an IQ evaluation using the Wechsler Intelligence Scale for Children III – WISC III (Wechsler, 1991);
e) Normal or corrected to normal vision; and
f) Studying in a school where English was the primary medium of instructions.

The LD group was recruited from intervention centers in Mumbai where services for hearing assessment, speech therapy, special education, psychiatry and occupational therapy are provided on the premises. These children were assessed and diagnosed for LD at the B.Y.L. Nair Ch. Hospital and T.N. Medical College, Mumbai. The participants were recruited after they completed the assessment process and were diagnosed for LD. The assessment battery used at the B.Y.L. Nair Ch. Hospital and T.N. Medical College included patient history, Woodcock Johnson III Test of Achievement, WISC III, motor skills assessment, and written communication tests.

The TD group was recruited from private schools in Mumbai. These children demonstrated normal academic performance and were free of learning disabilities, attention-deficit hyperactivity disorder, or other specific learning disabilities based on school records.

Procedure and Stimuli

Participants were tested in a double-walled, double-floored sound treated booth. Pure tone audiometry, immitance audiometry, and the three AP tests Dichotic Digit (DD), Duration Pattern Sequence (DPS) and Random Gap Detection (RGD), in standard and extended time were administered in one 120-minute session. AP tests were pre-recorded recorded on a CD. The CD was played on a Sony CD player and routed through the GSI - 61 (Garson – Stadler, Inc.) diagnostic audiometer to TDH - 50 earphones.

American normative information was used. The DD and DPS scores were considered "pass" if the scores were within 2 *SDs* of the mean (for norms, see Bellis, 2003). For the RGD, a gap detection threshold of 20 ms or less was regarded as pass (Keith, 2000). Children who scores 2 *SDs* below mean on two tests were classified as having APD (ASHA, 2005).The three tests were administered with the standard test procedure and with a response time extended by 2 seconds. The extended timed test was constructed using Audacity software and recorded on a CD (Table 2.1).

Table 2.1. Standard and Extended Response Time Utilized for Three AP Tests

Tests	Standard Response Time	Extended Response Time
Duration Pattern Sequence	3 Sec	5 Sec
Dichotic Digit	4 Sec	6 Sec
Random Gap Detection	4.5 Sec	6.5 Sec

Auditory Processing Tests

1. Dichotic Digit (DD): DD is a test of binaural integration (Sharma, Purdy, & Kelly, 2009). A two-digit dichotic test with three practice items was utilized for this study. The test was administered at a presentation level of 50 dB SL (re: spondee threshold). The test consists of naturally spoken digits from 1 to 10 excluding 7. A different pair of digits was presented simultaneously to each ear and the participant was instructed to repeat all four digits in any order (Kimura, 1961; Musiek, Wilson, & Pinheiro, 1979). The test consisted of 20 total stimuli (digits in English) or 80 digits in all (40 per ear) with three practice items. Percent correct is calculated for each ear; each correct digit is worth 2.5% (40/100).
2. Duration Pattern Sequence (DPS): DPS is a test of auditory temporal processing and patterning (ASHA, 2005). DPS presents three consecutive 1000Hz tones and 300 ms intertone intervals with two different durations. The tone durations were 500 ms for the long stimulus and 250 ms for the short stimulus. Each tone has a

10 ms rise-fall time. Participants were instructed to listen carefully and verbally report the pattern of tones they heard. The responses must be either: LONG LONG SHORT, LONG SHORT LONG, LONG SHORT SHORT, etc. Examples were given using both voice and gesture (Musiek, Baran, & Pinheiro, 1990; Musiek, 1994). The test was administered binaurally with 6 practice items and 30 test items at a presentation level of 50 dB SL (re: 1000 Hz threshold). Percentage correct was calculated; each item was worth 3.3%.

3. Random Gap Detection (RGD): RGD assesses the ability to detect temporal changes in auditory stimuli (Madden & Feth, 1992). RGD consists of five sets of stimuli. The first set is a practice set followed by four sets using tones of different frequencies (500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz). The duration of each tone is 15 ms and the gap between two tones ranges from 0 to 40 ms. Participants verbally indicated whether they heard one or two tones. The test was administered at 55 dB HL binaurally. RGD were calculated for each frequency by identifying the smallest gap at which the listener was able to identify two tones consistently. Scores were also measured for the percent of correct responses. Three AP tests and two conditions were counterbalanced in terms of sequence of the presentation.

Data Reduction and Analysis

Descriptive statistics, including mean, standard deviation, and median scores, were derived for all three tests in both testing conditions. These data were then subjected to statistical testing. A series of 2 (group) x 2 (condition) repeated measures of analysis of variance (ANOVA) were conducted for the three AP tests. The level of significance for repeated measures ANOVA was fixed at 0.01. Effect size was measured using eta squared ($\eta 2$). Effect size was considered medium ≥ 0.13, and large at ≥ 0.26. Follow-up analysis was done using paired t-test to compare the test scores in standard and extended time conditions. The paired t-test analysis was done for both the LD and TD groups. For the paired t-test, the level of significance was fixed at 0.01. Effect size for paired t-test was measured using Cohen's *d.* Cohen's *d* was considered medium ≥ 0.50 and large at ≥ 0.80.

Repeated measure ANOVA was used to compared first and second-half test performance. Follow-up analysis was done using paired *t*-test to compare the test scores from the 1st and 2nd halves in standard and extended time conditions. The paired t-test analysis was done for both LD and TD groups. Level of significance was fixed at 0.01 for paired t-test.

Results

Effect of Extended Time on AP Test Scores

Table 2.2 and Table 2.3 presents the means and SDs for the three AP measures, DD, DPS, and RGD for LD and TD group respectively. The effects of group and condition were analyzed with three 2 (group) x 2 (condition) repeated measured ANOVAs. As expected, the TD group performed significantly better than the LD group on all three measures. On the DD task, the main effect of condition (standard/extended time) was significant, F (1, 34) = 26.30, $p < 0.01$, $\eta 2$= 0.43, but the group x condition interaction was also significant, F (1, 34) = 13.36, $p < 0.01$, $\eta 2$= 0.282. As can be seen in figure 1.1, the performance of the LD group improved in the extended time condition whereas there was no change in the performance of the TD group. A paired *t*-test indicated that the LD group's improvement was significant with a large effect size, (t (23) = -6.64, $p < 0.01$, d = -1.06). Effect of condition was significant for DPS, F (1, 34) = 8.10, $p < 0.01$, $\eta 2$= 0.19, indicating that the participants performed differntly in two time conditions. However, the interaction between group and condition was not significant, F (1, 34) = 1.91, p = 0.176. No effect for condition was found for the RGD task.

Table 2.2. Effect of Extended Response Time on the AP Test Scores of the LD Group

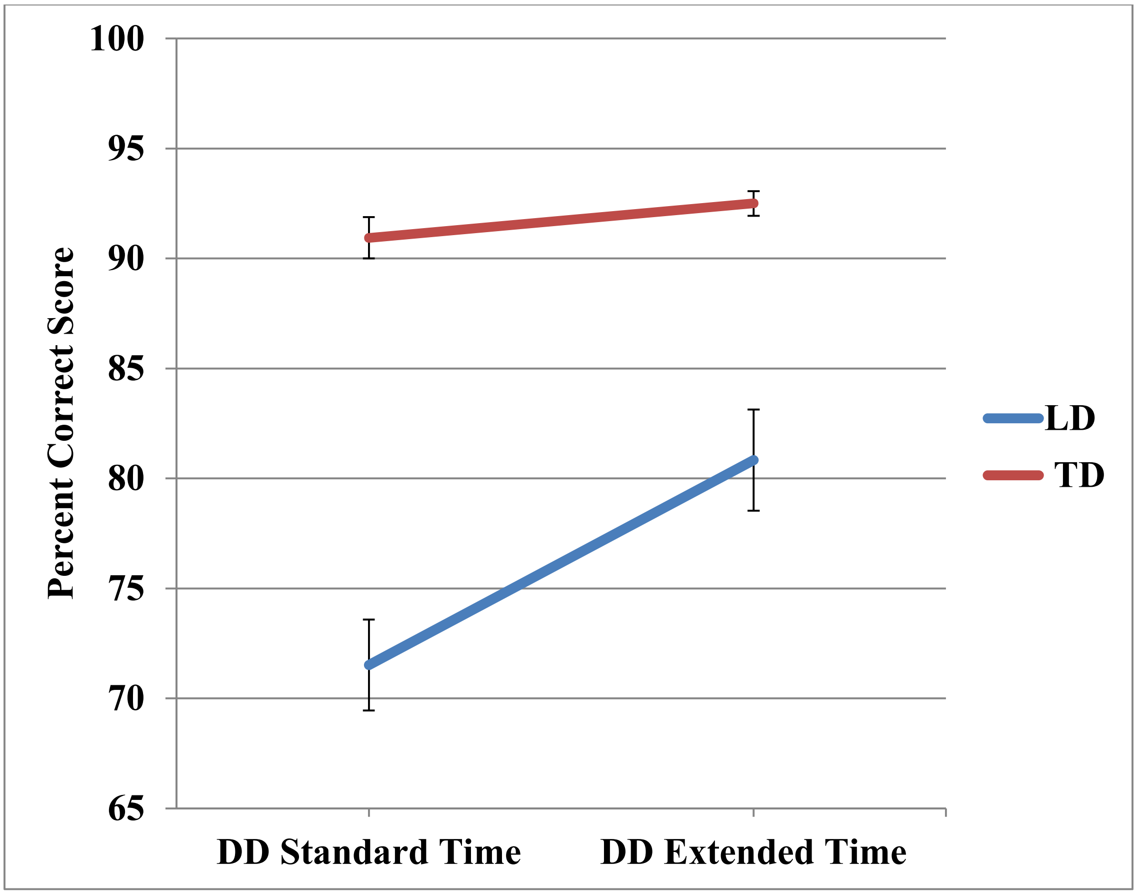
	DDT		DPS		RGD	
	Std	Ext	Std	Ext	Std	Ext
Mean	71.51	80.83	43.33	50.55	68.28	68.63
Median	71.87	83.12	41.66	51.66	81.94	80.55
SD	10.12	11.25	19.26	23.84	28.71	28.76
N	24	24	24	24	24	24
P	**0.000***					

Note. Values in bold with * indicate statistical significance $p \leq .01$.

Table 2.3. Effect of Extended Response Time on the AP Test Scores of the TD Group

	DDT		DPS		RGD	
	Std	Ext	Std	Ext	Std	Ext
Mean	90.93	92.50	83.05	85.55	92.12	91.66
Median	92.5	91.87	81.66	86.66	95.83	97.22
SD	4.58	2.76	7.71	8.32	9.16	9.69
N	12	12	12	12	12	12
P	0.155					

Figure 1.1. Percentage Score for Dichotic Digit Test under Standard and Extended Time Conditions for LD and TD Groups



Note: Error bars represent the standard error of mean.

Differences in Scores with Extended Time

Difference scores between performance on the standard and extended time conditions were calculated for each participant for the DD and DPS tasks. A 10% change in score was considered to be a clinically meaningful difference whereas as a 20% change was considered to be a large difference. For the DD task, a 10% change was equivalent to 7.1%; 20% was 14.2%. For the DPS task, a 10% change was equivalent to 4.3%; 20%

was 8.6%. For DD, 16 participants showed at least a 10% improvement and 11 participants showed at least a 20% improvement in performance. No student showed a reduction in score of at least 10%. For the DPS test, 17 participants showed at least a 10%, and 16 participants showed at least a 20% increase in scores with extended time. Six participants showed at least a 10%, and 4 participants showed at least a 20% reduction in scores for DPS (Table 2.4). Further analysis was done to measure the number of participants who showed change in scores for both DD and DPS tests. 11 participants showed at least a 10% increase and 7 participants showed at least a 20% increase in score on both tests.

Table 2.4. Participants who Showed Significant Change in their Performance between Normal and Extended Time Conditions

LD (N=24)	Scores	≥10%	≥20%
DD	Increased	16	11
	Reduced	0	0
DPS	Increased	17	16
	Reduced	6	4
Both DD and DPS	Increased	11	7
	Reduced	0	0

AP Test Failure and APD Diagnosis

On the basis of AP tests scores and reported age norms, children from LD group were classified as pass or fail on each AP test under standard response time and extended response time conditions (Table 2.5). For DD and DPS, more participants failed the test in standard time condition compared to extended time condition. For RGD the test failure rate was same in both conditions. Twenty-one students failed at least two tests in the standard time condition compared to only 14 for the extended time condition (21---14), a difference of 7 students.

Table 2.5. Participants Failed on AP Tests on Normal and Extended Time Conditions

	DDT		DPS		RGD		Failed ≥ 2 tests	
	Std	Ext	Std	Ext	Std	Ext	Std	Ext
LD (N =24)	22	14	22	16	7	7	21	14

Effect of Practice on AP Test Scores

Scores from the first and second parts of the three AP tests were compared to determine whether there was any learning or practice effect for the two groups in the two conditions. Descriptive statistics for first and second halves of the three test scores for the LD and TD group for standard and extended time conditions are reported in Table 2.6, 2.7, 2.8, and 2.9. A series of 2 (condition-standard/extended) x 2 (test part-first/second) found no significant differences between the two parts of the three tests for the two conditions for both the TD and LD groups.

Table 2.6. Practice Effect on the AP Test Scores of LD Group with Standard Time

	DDT		DPS		RGD	
	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half
Mean	69.37	73.64	45.83	40.83	68.05	68.28
Median	68.75	77.50	43.33	40.00	83.33	80.55
SD	9.89	12.64	24.34	16.12	28.38	29.55
N	24	24	24	24	24	24

Table 2.7. Practice Effect on the AP Test Scores of LD Group with Extended Time

	DDT		DPS		RGD	
	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half
Mean	81.25	80.41	50.27	50.83	68.05	69.21
Median	85.00	81.25	46.66	53.33	80.55	83.33
SD	11.51	11.48	24.78	23.81	28.76	29.02
N	24	24	24	24	24	24

Table 2.8. Practice Effect on the AP Test Scores of TD Group with Standard Time

	DDT		DPS		RGD	
	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half
Mean	91.04	90.83	83.88	82.22	90.74	93.51
Median	91.25	92.50	80.00	80.00	94.44	97.22
SD	3.91	6.33	11.17	9.13	10.41	8.8
N	12	12	12	12	12	12

Table 2.9. Practice Effect on the AP Test Scores of TD Group with Extended Time

	DDT		DPS		RGD	
	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half
Mean	92.29	92.70	86.11	85.00	91.66	91.66
Median	92.50	92.50	86.66	83.33	97.22	97.22
SD	3.91	3.91	9.62	8.58	9.90	9.90
N	12	12	12	12	12	12

Differences in Scores between Two Halves on AP Tests

Difference scores between performances on first and second part of the three AP tests were calculated for each participant. A clinically meaningful difference was considered at a 10% change, and a large difference was considered at a 20% change in scores. Comparison was done in both standard time condition and extended time conditions. In standard time condition, for the DD task, a 10% change was equivalent to 6.9%; 20% was 13.8. For the DPS task, a 10% change was equivalent to 4.5%; 20% was 9%. For the RGD task, a 10% was equivalent to 6.8%; 20% was 13.6. Table 2.10 shows the positive and negative changes in scores for all three AP tests in standard time condition. An increase in scores of at least a 10% was observed for 12 students on the DD task; 7 students showed a 20% increase. On the DPS task increase in scores of at least a 10% was observed for 9 students; 9 students showed a 20% increase. On the RGD task increase in scores of at least a 10% was observed for 3 students; 3 students showed a 20% increase. Decrease in scores at least 10% was observed for 4 students on DD task; 3 students showed a 20% decrease.

On the DPS task decrease in scores of at least a 10% was observed for 10 students; 10 students showed a 20% decrease. On the RGD task decrease in scores of at least a 10% was observed for 2 students; 2 students showed a 20% decrease.

Table 2.10. LD Participants who Showed Significant Change in their Performance between First and Second Half for Standard Time Test Condition

LD (N=24)	Scores	≥10%	≥20%
DD	Increased	12	7
	Reduced	4	3
DPS	Increased	9	9
	Reduced	10	10
RGD	Increased	3	2
	Reduced	3	2

In extended time condition, for the DD task, a 10% change was equivalent to 8.1%; 20% was 16.2. For the DPS task, a 10% change was equivalent to 5%; 20% was 10%. For the RGD task, a 10% was equivalent to 6.8%; 20% was 13.6. Table 2.11 shows the positive and negative changes in scores for all three AP tests in extended time condition. An increase in scores of at least a 10% was observed for 1 student on the DD task. On the DPS task increase in scores of at least a 10% was observed for 8 students; 7 students showed a 20% increase. On the RGD task increase in scores of at least a 10% was observed for 6 students; 3 students showed a 20% increase. Decrease in scores at least 10% was observed for 2 students on DD task. On the DPS task decrease in scores of at least a 10% was observed for 8 students; 7 students showed a 20% decrease. On the RGD task decrease in scores of at least a 10% was observed for 3 students; 1 student showed a 20% decrease.

Table 2.11. LD Participants who Showed Significant Change in their Performance between First and Second Half for Extended Time Test Condition

LD (N=24)	Scores	≥ 10%	≥ 20%
DD	Increased	1	0
	Reduced	2	0
DPS	Increased	8	7
	Reduced	8	7
RGD	Increased	6	3
	Reduced	3	1

Discussion

The present study examined whether increasing response time on three AP tests would significantly improve performance in children with learning disabilities and their typically developing peers. Also examined was whether there was any difference on the first and second parts of the three AP tests that might reflect a learning or practice effect.

As expected, the TD group performed significantly better than LD group on all three AP measures. These findings are consistent with a large body of research showing that children with LD perform below age levels on measures of temporal processing and dichotic listening (Sharma et al., 2009; Zaidan & Baran, 2013). Comparisons of the standard and extended-time conditions revealed only one significant difference, The LD group's performance significantly improved on the DD task in the extended time condition. Subsequent analyses of individual subject data showed that more than half of the children with LD benefitted from the extended time on the DD test as well as the DPS test. For the DD and DPS tasks about two-thirds of the students showed a clinically significant (≥10%) improvement in performance. Out of 24, 11 children showed a clinically significant improvement on both DD and DPS tests. A large improvement (≥ 20%) in scores was observed in 11 participants for DD and in 16 participants for DPS. Seven participants showed a large improvement on both DD and DPS tests. The RGD test showed no change in scores with extended time. A difference was also found in the test failure rate when scores were compared to age norms. Fewer participants failed AP tests in the extended time condition than the standard time condition.

The findings of this study indicate that the extended time helped children with LD improve their scores on two out of three AP measures. Not coincidentally, the two tests that showed improvement, DD and DPS, had higher processing demands than the test showing no improvement, RGD. Students with LD have been shown to have deficiencies in attentional, memory, and language processes (Denckla & Rudel, 1974; Hari & Renvall, 2001; McGrady & Olson, 1970; Rudel et al., 1981; Wolf, 1986; Wolff, Michel, & Ovrut, 1990; Wolff, Michel, Ovrut et al., 1990; Wolff et al., 1984).

Table 2.12 presents the different auditory, language, attentional, and motor demands required on the three AP tests. DD test requires a person to switch attention between two ears and repeat the four digits (words) after each test item. The DPS test requires labeling three tones. In contrast to DD, which uses speech, DPS uses tones, which are non-linguistic stimuli. However, responses on these tests require 3-4 words.

Table 2.12. Potential Factors Contributing to the Test Failure Rate

Tests	Auditory Process	Linguistic Component	Attentional Factor	Response Length
DD	Binaural integration	Words	Divided attention and Sustained attention	4 words
DPS	Auditory temporal processing and pattern test	-	Sustained attention	3 words
RGD	Auditory temporal processing and pattern test	-	Sustained attention	1 word

The test with the highest processing demands, DD, was associated with the largest change in performance in the extended time condition. The test with the least processing demands, RGD, showed no change in performance in the extended time condition. The change in score with extended time was more for the test with the highest demands (DD), followed by the test with fewer demands (DPS). In contrast to DD and DPS, RGD has the lowest attentional, linguistic and motor demands. For RGD, a participant has to listen to a tone (non-linguistic) and respond with a single word, saying one or two. Having fewer stimuli in a test item with shorter response length (one word) makes the test less demanding. Therefore a significant change in score with extended time for RGD test was not found.AP tests are known to be sensitive to non-auditory factors such as attention and working memory (Cook et al., 1993; Dawes & Bishop, 2009; Lum & Zarafa, 2010),. It is difficult to remove these factors completely from the behavioral AP assessment procedures; however, they can be minimized. As the ASHA 2005 position statement on APD notes, APD is a deficit in neural processing of auditory stimuli that is not due to deficiencies in higher cognitive and linguistic abilities. Reducing the higher-level language and cognitive demands of AP tests will improve the diagnostic sensitivity of these tests in identifying individuals with APD.

There was no evidence of learning or practice when the first and second half of the test items were compared. This finding is not surprising, given that previous research (e.g., Marler et al., 2001; Schaffler et al., 2004) has found that learning and practice effects only occur when AP tests were presented over multiple days and intervals.

Summary

The findings of this study confirmed that the extended response time significantly improved the performance of children with LD on two out of three AP measures. Using extended response time would reduce the cognitive linguistic confounds and could help in differentiating children who have APD from those who perform poorly on AP measures due to cognitive linguistic demands. No difference in performance was found when the two halves of AP tests were compared. This could be an indication that for LD children, half test items are not enough to improve their performance.

CHAPTER V

IMPACT OF DIFFERENT DIAGNOSTIC CRITERIA ON RATE OF APD DIAGNOSIS

Abstract

Purpose: The purpose of this study was to determine whether or not the current sample of participants assessed for AP was normally distributed between 1 SD and 2 SD below mean. The study measured the differences in test failure rate and APD diagnostic rate for children using two different cutoff criteria: 1 SD below mean, as recommended by Central Test Battery (CTB) and 2 SD below mean, as recommended by ASHA (2005).

Method: Demographic data and CTB test scores were collected retrospectively for 98 children with a median age of 9 years (min = 7, max = 11), who had normal hearing sensitivity, normal middle ear function, and no neurological disorders. Frequency measurement and chi-squared test were utilized for the analysis. A retrospective single-observation design was used.

Results: The sample assessed for AP demonstrated a normal distribution between 1 and 2 SD. There was a higher failure rate on CTB using the 1 SD cutoff criteria than 2 SD. The diagnostic rate for APD was also higher using the 1 SD cutoff criteria than 2 SD.

Conclusions: Current CTB criteria of a 1SD below mean cutoff score leads to higher diagnosis of individuals for APD. Considering the wide usage of these tests in the US, it is important to create awareness among audiologists. The audiologists using CTB

should reconsider cutoff scores and make them 2 SD below mean in compliance with ASHA guidelines. Key Words: central test battery, auditory processing disorder, SSW, phonemic synthesis, speech in noise

There is a problem of who should be identified as having an auditory processing disorder (APD). This problem is of central importance to both clinicians and researchers within the field of audiology. Standardized auditory processing (AP) tests are used to identify as children having APD. In the absence of a gold standard, it is commonly assumed that children obtaining lower scores on AP tests have APD. Results of AP tests can be interpreted using a norm-based approach (intersubject) or an intra-subject (patient-referenced) comparison (Musiek and Chermak, 2014). The current study focuses on the norm-based approach. For a norm-based approach, the test scores of the participant are compared with the scores of a group of normal participants. The cutoff scores were derived using mean and standard deviation (SD) from the scores of normal or typically developing participants.

There is no agreement among researchers and clinicians about using criteria for cutoff scores. Some researchers support 2 SD below mean as the cutoff point on AP tests to classify children as pass or fail on the test (AAA, 2010; ASHA, 2005; Chermak and Musiek, 1997; Musiek and Chermak, 2014). However, others support using 1 SD below mean as the cutoff point on AP tests to classify children as pass or fail on the test (Katz, 1992). In the presence of two different criteria for cutoff scores, clinicians identify children with APD at different rates.

To diagnose APD, audiologists perform a set of tests (test battery) which assesses various auditory processes that includes auditory discrimination, temporal aspects of audition, localization and lateralization, auditory pattern recognition, auditory performance in competing acoustic stimuli and auditory performance with degraded acoustic signals (ASHA, 2005). There is freedom for audiologists to select a test battery based on the referral complaint, age, motivation level, and other cognitive linguistic factors. The clinical guidelines developed by the American Speech and Hearing Association (ASHA) and the American Academy of Audiology (AAA) give detailed recommendations about the test principles, types of AP tests, and diagnostic criteria (AAA, 2010; ASHA, 2005).

There are numerous tests currently available for clinicians to use to assess AP. The Central Test Battery (CTB) is one of the most widely used test batteries in the United States (US) to diagnose APD (Chermak, Traynham, Seikel, & Musiek, 1998; Schow & Chermak, 1999). The CTB, developed by Katz (1992), consists of three widely used tests: Staggered Spondaic Word (SSW), Phonemic Synthesis Test (PS), and Speech in Noise (SN) test. Audiologists prefer to use CTB for variety of reasons.

a. It provides ready access to a test battery that assesses different auditory processes. As all tests are recorded on one CD, it saves time. Using tests from different CDs may be time consuming.

b. All three tests are normed for a wide age range. CTB can be used to assess AP in children as young as age 5.

c. Phonemic Synthesis test provides quantitative as well as qualitative metrics. Qualitative measurements give an additional source of information about participant's performance on a test (information about the response, for example, reversal, delay, perseveration, quick, etc.). Qualitative measurements also give confidence to audiologists when making a diagnosis and making recommendations for treatment.

d. The CTB provides a software tool to identify pass or fail status based on the test scores (provided by clinician) and inbuilt age norms.

e. The software categorizes auditory processing problems into four groups based on the Buffalo Model (Katz, 1992).

1. Decoding
2. Tolerance fading memory
3. Integration
4. Organization

f. These four categories are useful in making recommendations for the management of APD.

The CTB recommends using different criteria for age norms in children and adults. The central auditory nervous system is not fully matured in young children; therefore below the age of 12, CTB uses age specific norms. For age 12 and above, performance on CTB becomes adult-like; therefore norms are the same from age 12 to 59. CTB recommends different cutoff points for children and adults to decide pass or fail status on a test. It was reported that the SD on a test score for 7-year-old children was

11% compared to 4% for adults. Because children have relatively large SDs even within the same age group, Katz, hypothesized that using 2 SD below the mean as the cutoff criteria would cause too many APD children to not be identified. Therefore, a 1 SD cutoff was recommended for children. However, in adults, 2 SD below the mean as cutoff was recommended (Katz, 1992).

While the cutoff score recommended for children on AP tests by the ASHA and AAA guidelines is 2 SD below the mean, the CTB recommends 1 SD below the mean. It is evident that there is no consensus about using cutoff scores among clinicians across the country. The discrepancy in the use of cutoff scores as recommended by AAA, ASHA, and CTB, and its impact on test failure rates, as well as on APD diagnostic rate, has not been reported before. It is an important issue to address to create awareness among audiologists who use CTB to diagnose APD.

The purpose of this study was two fold. First, determining whether the sample of participants assessed for AP is normally distributed between 1 and 2 SD. To determine this, participants were classified as pass or fail using both 1 SD below mean and 2 SD below mean criteria. The difference in the number of participants who failed using two criteria were then compared with the expected difference in the normal distribution curve. This approach will help in testing the hypothesis made by Katz (1992) that using 2 SD criteria will miss a lot of children with AP. Secondly, we also want to measure the difference in AP test failure rates and APD diagnosis rate using the two criteria to determine how much difference it makes clinically. This will help us in understanding whether using two criteria increases the risk of misidentifying children.

Method

Records of children assessed for AP at the Speech and Hearing Clinic at University of North Carolina Greensboro (UNCG) were retrieved and analyzed retrospectively. Permission to access patient files for the purpose of research was obtained through the UNCG Institutional Review Board (IRB). Demographic data obtained included case history, age, and AP and hearing test results.

Participants

Out of the 203 participants, 98 were included in this study. The inclusion criteria for participant selection were as follows. Each participant had to have or demonstrate

a) Normal hearing sensitivity (thresholds < 25dB HL between frequencies 250 Hz and 8k Hz, measured at octaves);
b) Normal middle ear function with compliance ≥ 0.2 ml, pressure between -100 and +50 daPa (Jerger, 1970);
c) No neurological disorders;
d) Completed their assessment between August 2003 and September 2011; and
e) English as their primary language.

Demographic data and three CTB test scores were collected retrospectively from 98 children (F=36, M=62), with a median of age 9 years (min= 7, first quartile=7, third quartile=10, max=11).

AP Test Battery

Test scores for three CTB tests (SSW, PS and SN) were extracted. All tests were performed by qualified state licensed audiologists, in a sound treated booth and on calibrated instruments. Details about the administration protocol of the tests are reported in Table 3.1. Not all children were tested with all three tests.

Table 3.1. Central Test Battery and Test Protocols

AP Test	Protocol
Staggered Spondaic Word Test (SSW)	Level: 50 dB SL in both ears Type: Dichotic Stimuli: Spondee words Score: Count the incorrect responses
Phonemic Synthesis (PS)	Level: 50 dB SL in both ears Type: Binaural Stimuli: Strings of discrete phonemes Score: Count the incorrect responses
Speech in Noise (SN)	Level: 40 dB SL with SNR +5 Type: Monaural Stimuli: Monosyllabic words Score: Percent correct score for each ear

Data Reduction and Analysis

The raw scores for three tests of CTB were retrieved from patient files for the retrospective analysis. Test scores for the measure components of the test were included for the analysis. For the SSW test, five components (right non-competing (RNC), right competing (RC), left competing (LC), left non-competing (LNC) and total sore) were included. Quantitative and qualitative scores for the PST and right and left scores for SN tests were included. Comparison with age norm was performed for each component of the test. The participant was classified as fail if they failed any one component of the test. For example, if a child failed on any one of the five components of the SSW test then the child was classified as fail on the SSW test. Age norms (Katz, 1992) for these tests were included in the analysis from the test manual; we calculate both cutoffs at 1 SD and 2 SD below the mean. The analysis included the following steps:

1. The raw scores were compared to 1 SD below mean cutoff to classify children as pass or fail on a test (Katz, 1992).
2. The raw scores were compared to 2 SD below mean cutoff to classify children as pass or fail on a test (AAA, 2010; ASHA, 2005).
3. Out of three tests, the number of tests failed by each child in step 1 was calculated.
4. Out of three tests, the number of tests failed by each child in step 2 was calculated.
5. For both criteria, children who failed 2 or more tests were classified as APD.

Descriptive and frequency analyses were used to compare the failure rate on each test and APD diagnostic rate. Chi-squared analysis was utilized to compare the difference in failure rate using two criteria on test score with the expected difference using normal distribution. The level of significance for chi-square was fixed at 0.05.

Results

The failure rate on AP tests was analyzed in two ways. First, the failure rate on the component of each test was measured using cutoff scores at 1 SD and 2 SD below mean (Table 3.2). There was a difference in test failure rate for all tests in all the components using cutoff scores of 1 SD and 2 SD. The failure rate was higher using 1 SD. Second, the failure rate on each test was measured. Table 3.3 shows the failure rate (%) on each test. Children were classified as fail on a test if they failed at any one component of the test. Failure rate for each test was then measured using cutoff scores at 1 SD and 2 SD below mean. The test failure rate was higher using cutoff scores at 1 SD compared to 2 SD (Table 3).

Table 3.2. Failure Rate for Components of Each of the Three CTB Tests Using Cutoff Scores at 1 SD and 2 SD

Tests		Children Failed for Cutoff 1 SD (%)	Children Failed for Cutoff 2 SD (%)
	RNC	48.5	39.2
	RC	64.9	51.5
SSW (N= 97)	LC	77.3	66.0
	LNC	64.9	40.2
	Total	82.5	70.1
PST (N = 97)	Quantitative	51.5	36.1
	Qualitative	61.1	41.7
SN (N = 69)	Right Ear	75.4	56.5
	Left Ear	76.8	53.6

Table 3.3. Percent Failure Rate for Tests (any way) and APD Diagnostic Rate Using Cutoff Scores at 1 SD and 2 SD

Tests	Children Failed for Cutoff 1 SD (%)	Children Failed for Cutoff 2 SD (%)	Difference	Expected Difference	Chi-square (X^2, p)
SSW (N=97)	93.8	81.4	12.4	13.59	$X^2 = 1.4$ $p = 0.51$
PST (N=97)	58.8	41.7	17.1	13.59	
SN (N=69)	84.1	68.1	16	13.59	
Failed 2 Tests (N= 68)	86.8	66.2	20.6		

The difference in failure rate using the 1SD and the 2SD criteria of AP sample was compared with the expected difference when normal distribution was utilized. In a normally distributed sample, around 15.86 % of participants fall below 1SD from mean cutoff, and around 2.27 % of participants fall below the cutoff of 2 SD below mean. That means 13.59 % (15.86 – 2.27 = 13.59) of participants will fall between 1SD and 2SD. To test Katz's (1992) hypothesis that using 2 SD criteria will lose many children with APD, we compared the differences in test failure rate using two criteria (1SD and 2SD cutoff) with the expected difference of 13.59%. A chi square analysis of goodness-of-fit was performed to determine whether the AP sample is part of normal distribution. The participant distribution on the three AP tests was part of the normal distribution, X^2 (2. N= 98) =1.43, p = 0.51.

Children were classified as having APD if they failed more than two AP tests (Table 3.3). More children were classified as having APD when the 1 SD cutoff score (87.5%) was used compared to 2 SD (68.8%).

Discussion

The purpose of this study was to determine whether the sample of participants assessed for AP was normally distributed between 1 and 2SD below mean. The study also measures the failure rate and the APD diagnostic rate for CTB using two cutoff criteria: 1 SD below mean, as recommended by Central Test Battery (CTB) and 2 SD below mean, as recommended by ASHA (2005).

Inconsistencies and lack of consensus on defining a cutoff point on AP tests is evident among the audiologists across the country. CTB recommends using 1 SD cutoff for children whereas ASHA and AAA recommend using 2SD as cutoff score for AP tests. This difference in cutoff scores has a profound impact on classifying children for failure on tests as well as diagnosing them for APD. The APD diagnostic rate was much higher using 1SD cutoff score (86.8%) compared to 2 SD cutoff score (66.2 %).

The current study tested Katz's hypothesis that many children with APD will be missed using the 2 SD criteria. It was found that the sample of children assessed for AP is part of normal distribution. This implies that by changing the cutoff point from 1 SD to 2 SD we are including more children from normal distribution. If Katz's hypothesis had been true then we would have found a distribution with more children in between 1 SD and 2 SD below mean cutoffs compared to normal distribution. Such distribution could have been a strong support for using 1SD below mean as criteria for failure and identifying children who have APD. Since there was no difference in the distribution, it was concluded that when using the 1 SD criteria more children who are part of normal distribution gets a diagnosis of APD.

Internationally in psychology, sociology and behavioral sciences, the 2 SD cutoff was used to classify children as a pass or fail on behavioral tests. 2 SD was adopted as standard because statistically this point is considered to differentiate between normal and abnormal performances with more confidence (Musiek and Chermak, 2014). Because of the difference in failure rate and APD diagnostic rate using different cutoff points on CTB, we recommend to audiologists who use CTB for APD diagnosis to reconsider the cutoff scores for children and make them 2 SD below mean in compliance with AAA (2010) and ASHA (2005).

Summary

Using different cutoff criteria for AP tests increases risk of misidentifying children for APD. The current sample of children assessed for AP indicates a normal distribution between 1 and 2 SD. Using 1 SD below mean criteria adds more children from normal distribution to identify them as APD. Use of 2 SD below mean as cutoff criteria is supported.

CHAPTER VI

SUMMARY

These three studies on the assessment and diagnosis of APD investigated the impact of test selection, test administration and use of different cutoff criteria on the APD diagnosis. In this research portfolio, the question concerning which tests should be used in an AP assessment battery was studied by measuring AP test failure rates and variation of APD diagnosis rate depending on the type of tests (speech/non-speech) included in the diagnostic criteria. The second question concerning factors in test administration was examined by looking specifically at the effects of response time and practice on AP tests in children with LD. Finally, the third question was studied by measuring the effect of cutoff criteria (1SD/2SD) on the diagnosis of APD.

The effect of AP test selection on diagnosis of APD was reported in "APD Diagnostic Rate Changes with Different Diagnostic Criteria Based on Inclusion of Speech and Non-speech Tests" (study 1). The purpose of this study was to quantify the failure rate of AP tests (speech and non-speech) and to measure the APD diagnosis rate using four different diagnostic criteria in a large sample of participants assessed for AP. The failure rate for AP tests varied from 14.3% to 76%. Overall the failure rate of non-speech tests was lower than speech tests. The APD diagnosis rate based on four diagnostic criteria ranged from 9.52% with strict criteria to 69.04% with lenient criteria. The diagnostic rate decreased when non-speech tests were added to the failure criteria.

Considering the large variability in failure rates of speech and non-speech tests, AAA and ASHA guidelines need to develop more specific recommendations regarding the need and value of inclusion of non-speech tests in AP assessment to avoid variation in the diagnostic rate. Inclusion of non-speech tests provides access to auditory processes other than speech, and is helpful in making sure that the deficit is not specific to speech processing, which could also be due to language impairment. Additionally non-speech tests would be useful in diagnosing individuals whose primary language is not English.

The non-speech tests included in study 1 assess two auditory processes, auditory pattern recognition (PPS, DPS) and auditory temporal processing (RGD). It is possible that deficits in auditory pattern recognition and temporal processing may not be as prevalent as deficits in binaural integration (SSW), binaural separation (CS) and sound blending (PS). Future studies need to determine the failure rates using non-speech tests which assesses different auditory processes such as binaural interaction (masking level difference, localization, lateralization) and auditory discrimination (difference limens for frequency and psychophysical tuning curves) to find whether failure rates are consistently lower for non-speech AP tests than speech based tests. Study 1 found a higher failure rate for speech tests (CS, SSW), which demand adequate functioning of the corpus callosum for inter-hemispheric processing of auditory information. It is possible that some children with APD primarily have a problem with the functioning of the corpus callosum. By using auditory, visual and tactile stimuli among individuals with APD, future research could determine the functioning of the corpus callosum.

Future studies could also investigate the differences in physiologic representation of speech and non-speech tests using auditory evoked potentials. The effect of test administration procedure and the important role of response time on AP measures were examined in “Effect of Varying Response Time and Practice on Measures of Auditory Processing” (study 2). Children with learning disabilities have slower response times and often perform below the level of typically developing peers on auditory processing measures. The purpose of the study was to further examine the effect of varying response times on the performance of children with LD/RD on AP tests. This study also assessed whether practice affected test performance. Standardized AP tests, DD, DPS and RGD, were administered with standard and extended time conditions to measure the effect of longer response time. It was found that LD children improved their performance on two out of three AP tests with extended time. Longer response time could reduce the cognitive linguistic confounds in AP assessment. The effect of practice was examined by computing differences in scores on the first half compared to the second half of the test. The practice effect was not significant.

The limitations of study 2 were small sample size and heterogeneous LD group. Additionally five out of eight ADHD participants had not taken medicine on the day of testing. Future studies need to be replicated in the US with a larger sample of children with dyslexia. The basic principle behind this study was to develop dynamic assessments for AP. Future studies could develop an assessment procedure where children will be assessed with different levels of help. The level of help would be retesting for the incorrect items from the test, providing extra time to respond and providing a visual feedback for the response. It would be crucial to study various populations at risk for AP, such as children with ADHD, LD and LI, and determine whether these children can improve their scores to pass AP tests. Dynamic assessments would be useful in differentiating children who are failing the test due to cognitive linguistic demands compared to children who have APD. Additionally, physiological correlates of behavioral symptoms using complex ABR and middle latency evoked potentials needs to be determined.

The effect of using different pass/fail criteria on APD diagnosis was measured in "Impact of Diagnostic Criteria on APD Diagnosis" (study 3). As reported in the literature review, currently many hearing health professionals and the manufacturers of AP tests themselves only recommend using one SD as a diagnostic cutoff. However, the use of only one SD in diagnosing a child with APD could increase the risk of over identification of APD. Thus, the purpose of this medical records review study was to determine whether or not a sample of participants previously assessed for AP was normally distributed between 1 SD and 2 SD. The study measured the amount of difference in test failure rate and APD diagnosis rate for children using two different cutoff criteria: 1SD below mean as recommended by CTB and 2 SD below mean as recommended AAA and ASHA. In contrast to Katz's hypothesis that more APD children will be missed if we use 2SD below mean as cutoff, the study found normal distribution of children between 1 and 2 SD. The study concluded that the current CTB criteria of a 1 SD below mean cutoff score, as predicted, leads to higher diagnosis of APD among children. Considering the wide usage of these tests in the United States, it is vital to increase the awareness among audiologists of the need to employ the criteria of 2 SD when assessing children and adults for APD. Manufacturers of AP tests and audiologists using CTB should reconsider cutoff scores and make them 2 SD below mean in compliance with AAA and ASHA guidelines. The future research needs to assess children who fall between 1 and 2SD below mean to understand the nature of their deficit using non-speech tests and middle latency responses.

The three studies indicate that there are some important gaps in the current guidelines recommended by AAA and ASHA in the assessment and diagnosis of APD. There is a need for more research to help establish more clear and optimal guidelines. Use of non-speech tests and tests with lesser linguistic inputs was supported for AP assessment in order to reduce the cognitive linguistic confounds. Administering AP tests with adequate response time was supported to reduce the effects of attention and working memory demands. Use of 2 SD below mean cutoff criteria was recommended in identifying children as APD.

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