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TESTING FOR AUDITORY PROCESSING DISORDER IN CHLDREN USING NEW NORMATIVE VALUES

by

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AUDIOLOGY DOCTORAL THESIS APPROVAL PAGE

This is to certify that the Audiology Doctoral Thesis prepared by Lauren M. Fong, B.S., Au.D. Candidate, entitled: Testing for Auditory Processing Disorder in Children Using New Normative Values has been approved by the thesis committee as satisfactory completion of the Audiology Doctoral Thesis requirement for the degree Doctor of Audiology (Au.D.)

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"…So stick to the fight when you're hardest hit, it's when things seem worst that you must not quit." –Anonymous

ABSTRACT

Testing for Auditory Processing Disorder in Children Using New Normative Values

Lauren M. Fong

The auditory processing disorder (APD) test battery used for diagnosing children with suspected APD is variable across clinics. Suggestions have been made for clinicians to use a minimum core battery with supplemental tests as needed; however, agreement on specific tests to include in this battery has not been made (AAA, 2010; Jerger & Musiek, 2000). New normative data were obtained using a battery developed with the suggestions provided in the AAA (2010) position statement in mind (McDermott, 2014).

It is well-known that the brain is complex; therefore, co-occurring disorders are not only possible but expected (Witton, 2010). The main aim of this study was to assess children with confirmed or suspected APD using the new normative data for test interpretation. Ten children, aged 7 to 12 years, with suspected or confirmed APD (SusAPD/APD group) were participants in this study. Their language, phonological processing, nonverbal intelligence, and attention were screened. The participants also received a hearing screening and a comprehensive auditory processing (AP) assessment.

Case history revealed that nine of the 10 participants also had suspected or previously diagnosed co-occurring disorders. The SusAPD/APD group's scores (screening tests and AP tests) were compared to the scores of the control group (CG) consisting of 20 age- (+/- 6 months) and gender-matched children. Results of the screening tests revealed that the CG performed significantly better than the SusAPD/APD group on the Test of Nonverbal Intelligence, 3rd Edition (TONI-3) and Phonological Awareness (PA) subtest of the Comprehensive Test of Phonological Processing

(CTOPP). The CG had better duration pattern test (DPT) scores for the right and left ears when compared to the SusAPD/APD group. The CG also had better mean scores for all screening tests except the IVA-CPT and for all AP tests in the temporal processing domain; however, this finding was non-significant. The use of the suggested screening tests will assist audiologists in making recommendations and modification to the AP test battery. The findings from this study also indicate the need for a larger sample size to further evaluate the sensitivity and specificity of the tests of AP used in this study.

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KEY TO ABBREVIATIONS

AAA: American Academy of Audiology

ABR: Auditory Brainstem Response

ADHD: Attention-Deficit/Hyperactivity Disorder

AFG: Auditory Figure Ground

ANSD: Auditory Neuropathy Spectrum Disorder

ART: Acoustic Reflex Threshold

APD: Auditory Processing Disorder

ASHA: American Speech-Language-Hearing Association

CANS: Central Auditory Nervous System

CELF-4: Clinical Evaluation of Language Fundamentals, 4^{th} Edition Screening Test

CG: Control Group

CRW: Compressed and Reverberated Words

CTOPP: Comprehensive Test of Phonological Processing

dB: Decibel

dB HL: Decibel Hearing Level

dB SPL: Decibel Sound Pressure Level

DL: Dichotic Listening

DPT: Duration Pattern Test

ESL: English as a Second Level

ENT: Ear, Nose and Throat

FPT: Frequency Pattern Test

HALL: Hearing and Listening Laboratory

Hz: Hertz

IQ: Intelligence Quotient

IVA-CPT: Integrated Visual and Auditory Continuous Performance Test

LD: Learning Disability

LI: Language Impairment

LiSN-S: Listening in Spatialized Noise- Sentences Test

MLR: Monaural Low Redundancy

ms: Millisecond

OME: Otitis Media with Effusion

RD: Reading Disorder

RGDT: Random Gap Detection Test

SLI: Specific Language Impairment

SLP: Speech-Language Pathologist

SNR: Signal-to-Noise Ratio

SusAPD/APD: Suspected Auditory Processing Disorder/ Auditory Processing Disorder

TEOAE: Transient Otoacoustic Emissions

TP: Temporal Processing

WRS: Word Recognition Score

Chapter 1

Introduction

Auditory Processing Disorder (APD) is a deficit in the processing of incoming auditory information in the presence of normal peripheral hearing (AAA, 2010; ASHA, 2005). People who have APD often have difficulty hearing in the presence of background noise, processing verbal information in challenging environments (i.e. rooms with reverberant surfaces), processing verbal directions, and/or localizing sound (Keith, 1999). APD can be a challenging disorder to diagnose accurately due to heterogeneity of the population with suspected APD. Also potentially confounding the diagnosis is the fact that APD can present similarly to common disorders such as Attention-Deficit Hyperactivity Disorder (ADHD), language impairment (LI), phonological processing, reading disorder (RD), and/or learning disability (LD) (Chermak, Hall, & Musiek, 1999; Sharma, Purdy, & Kelly, 2009). It can also co-occur with any of the disorders above. The brain is complex and its functions are not compartmentalized; therefore, co-occurring disorders are not only possible but are, in some ways, expected (Jerger & Musiek, 2000; Witton, 2010). This leads to the necessity of a comprehensive diagnostic assessment of the child often involving multiple professionals (Jerger & Musiek, 2000; Sharma et al., 2009; Witton, 2010).

Inclusion of other professionals is not always feasible (e.g., long waitlists to see specialists, insurance doesn't cover some assessments, etc.) therefore an audiologist may be the first professional that a person with suspected APD encounters. Due to the known co-occurring disorders in this population (e.g., Sharma et al., 2009), screening tests of nonverbal intelligence, language, and attention should be included in the audiologist's assessments when formal assessments have not been completed (Jerger & Musiek, 2000; Moore, Ferguson, Edmondson-Jones, Ratib, & Riley, 2010; Sharma et al., 2009).

A hearing test should always be performed on any person suspected of having APD, no matter the outcome of the screening tests (AAA, 2010). Although APD testing can be performed in the presence of peripheral hearing loss, results often need to be interpreted carefully due to the hearing loss potentially interfering with the patient's performance (AAA, 2010). Therefore, if hearing loss is present, the audiologist should evaluate how it impacts a child's listening abilities first and then, if appropriate, select tests of AP that can be used with people with hearing loss (AAA, 2010).

Once screening tests are completed and hearing loss (and other auditory disorders) has been ruled out, the next step is the APD evaluation. While other professionals (e.g., Speech-Language Pathologists (SLPs) and psychologists) can screen for APD or administer tests to identify weak auditory processing abilities in patients, they do not have the audiological tests (or equipment) that use acoustically modified stimuli to diagnose the disorder (Emanuel, Marczewski, Nagle & Fallon, in press). The American Speech-Language-Hearing Association (ASHA) and the American Academy of Audiology (AAA) classify APD as an auditory deficit, and therefore should only be *diagnosed* by an audiologist (AAA, 2010; ASHA, 2005).

The AP test battery includes several categories of listening tasks (e.g. monaural low redundancy [MLR], dichotic listening [DL], temporal processing [TP], sound localization and lateralization). Unfortunately, there is no universal test battery used by all audiologists for the APD assessment (Cacace & McFarland, 2005; Hall, 2007; Musiek et al., 2005; Musiek, Chermak, Weihing, Zappulla, & Nagle, 2011). To further complicate assessment, there are many tests that assess auditory processing abilities, but not all tests are highly sensitive and/or specific (AAA, 2010; Musiek et al., 2011). The audiologist needs to carefully consider appropriate tests for selection for the APD battery. Sensitivity and specificity are important when choosing tests. Additional consideration should be given when selecting tests regarding the patient's case history and presenting symptoms. Therefore, using tests to screen for other possible co-occurring disorders before assessing a child using a solid core battery for AP testing would potentially improve the diagnostic process and the recommendations for all children suspected of APD.

Chapter 2

Review of the Literature

Auditory Processing Disorder

Auditory processing disorder (APD) is a deficit in processing incoming auditory information (AAA, 2010; ASHA 2005; Jerger & Musiek, 2000). It is often characterized by difficulty hearing in the presence of background noise despite having normal peripheral hearing sensitivity although it can present itself differently between individuals (AAA, 2010; ASHA 2005; Jerger & Musiek, 2000; Rosen, Cohen, & Vanniasegaram, 2010). A diagnosis of APD is made after a comprehensive test battery identifies that perceived hearing difficulties are due to how the brain processes sound (ASHA, 2005; Chermak et al., 1999). ASHA (2005) defined APD in a technical report as:

> Difficulty in the following areas: sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition, including temporal integration, temporal discrimination, temporal ordering, and temporal masking; auditory performance in competing acoustic signals; and auditory performance with degraded acoustic signals (p. 3).

One or more difficulties in the above areas can be a result of APD. A deficit can affect everyday communication and occur anywhere from the cochlea to the cortex in the peripheral and central auditory systems, respectively (Hall, 2007; Jerger & Musiek, 2000; Keith, 1999). While APD can be present in children and adults the focus of this study is on children.

Signs and Symptoms of APD

The most common symptoms of APD are difficulty hearing in the presence of background noise or in an environment with reverberation (AAA, 2010; ASHA, 2005; BSA, 2011; Keith, 1999). Understanding rapid speech and verbal messages can also be made difficult by APD (i.e., multistep instructions). Other symptoms can include inappropriate, inconsistent responses to verbal messages and frequent requests for repetition (AAA, 2010; ASHA 2005; Keith, 1999). These difficulties can increase for children in classrooms with reverberant surfaces, noisy computers or fans, other children or teachers, and foot traffic noise. Children suspected of having APD may often respond to oral instructions with “what?” or “huh?” This is not uncommon as it may take children with suspected APD a longer time to process auditory information. Their processing abilities are essentially exhausted by the overabundance of incoming auditory stimulation that makes it difficult to separate and process the desired auditory signal, which can result in prolonged responses (AAA, 2010; ASHA, 2005; Keith, 1999). Children who have a poor auditory working memory often cannot follow multistep instructions or recall information (i.e. sequences of numbers and/or words) that are delivered orally (Colorado Department of Education, 2008; Florida Department of Education, 2001; Keith, 1999). Additionally, it may also be difficult to pay attention for an extended period of time, which may cause distraction (AAA, 2010; ASHA, 2005; Keith, 1999).

Epidemiology

Although the population with APD has been studied extensively, prevalence rates for it vary across the literature (Campbell, 2011; Golding, Carter, Mitchell, & Hood, 2004). A 2-3% prevalence rate estimated by Chermak and Musiek (1997) is commonly reported for the school-aged population (Campbell, 2011). There are several studies on the AP abilities of the elderly (Cooper & Gates, 1991; Golding et al., 2004). Some studies have attributed APD in the elderly population to neural changes in the aging auditory system. The evaluation of APD and possible causes in the school aged population may be difficult to evaluate due to the involvement of other systems (e.g., learning, language, cognition) (Martin & Jerger, 2005; Rosen et al., 2010; Vanniasegaram, Cohen, & Rosen, 2004). Chermak and Musiek (1997) estimated APD is two times more common in boys than girls. However, exact prevalence estimates are unknown due to undiagnosed cases and differences in diagnostic criteria (Chermak & Musiek, 1997).

APD can be a result of head trauma, severe illnesses, such as meningitis, and other types of neural conditions that affect the auditory system (Baran, 2009). These potential causes of APD are atypical in their presentation, because there is an identifiable site of dysfunction; this does not occur in the majority of APD cases (Baran, 2009). When a site of dysfunction can not be identified for persons suspected of APD, behavioral tests that have been administered to the above population to evaluate test sensitivity, specificity and efficacy are used (Jerger & Musiek, 2000; Keith, 1999; Musiek et al., 2011).

APD Assessment

The best practice approach to the APD assessment requires various assessment tools (e.g., questionnaires, case history, and subjective tests of auditory processing) (AAA, 2010). At minimum, a case history, questionnaires, direct observation of the patient, screening tests and a comprehensive audiologic evaluation are recommended

(AAA, 2010; ASHA, 2005; Jerger & Musiek, 2000). The case history and questionnaires typically involve input from caregivers and multiple professionals (e.g., teacher, speech-language pathologist, etc.). The case history can be a written form or provided orally.

Case history.

Before an APD battery is administered, an audiologist should complete an extensive case history (AAA, 2010; ASHA 2005). The case history assists in determining the presence of APD. A comprehensive case history will identify the patient's symptoms (in their own words) and concerns, impact on communication, and/or test selection (AAA, 2010). According to a survey by Emanuel, Ficca, & Korczak (2011), about 80% of audiologists with APD testing experience use a comprehensive case history for test battery modifications (i.e., adding and/or substituting tests as appropriate for the assessment of the child). The case history can also include information obtained by parents and/or teachers in the form of questionnaires.

Questionnaires.

Multiple questionnaires can be used to identify people at risk for APD (Keith, 1999; Yathiraj & Maggu, 2013). Parents and teachers can fill out questionnaires that describe auditory difficulties the child is experiencing both at home and in the classroom (Colorado Department of Education, 2008; Jerger & Musiek, 2000; Sharma et al., 2009). Input from caregivers provides the audiologist with information to supplement the results of the AP test battery (AAA, 2010). According to Wilson et al. (2011), questionnaires, specifically the Children's Auditory Processing Performance Scale (C.H.A.P.P.S.), Screening Instrument for Targeting Educational Risk (S.I.F.T.E.R.), and the Test of Auditory Perceptual Skills- Revised (TAPS-R), emphasize difficulties the child is experiencing. However, these questionnaires were unable to predict the outcome of APD assessment and therefore should not be used alone to determine if an APD evaluation is warranted (Wilson et al., 2011). Questionnaires are available to identify the child's auditory difficulties in relation to APD (Wilson et al., 2011). The following questionnaires may be helpful in the diagnosis of APD: C.H.A.P.P.S., Fisher's Auditory Problems Checklist, S.I.F.T.E.R., the Listening Inventory for Education, United Kingdom (L.I.F.E. UK), and the Children's Home Inventory of Listening Difficulties (CHILD) (see Appendix A for a description of these additional questionnaires) (Keith, 2004; Smoski, Brunt, & Tannahill, 1992; Smoski, Brunt, & Tannahill, 1998).

Direct observation.

Direct observation can be essential in assisting the audiologist with test selection, modification of the APD battery, and diagnosing APD (AAA, 2010; Florida Department of Education, 2001). When possible, the audiologist should observe the child in the classroom. Audiologists should look for difficulties with attention, cooperation in activities and lessons, and how the individual performs in both quiet and noisy situations (Colorado Department of Education, 2008; Florida Department of Education, 2001; Minnesota Department of Children, Families & Learning, 2003). According to a survey by Emanuel et al. (2011), 33% of audiologists who screen for APD use classroom observation as part of the screening process prior to administration of the APD test battery. Observations should take place where the child experiences the most difficulty. If this is not feasible, the audiologist should spend time observing the child during the case history portion of the appointment (AAA, 2010).

Comprehensive audiologic evaluation.

The audiological evaluation should, at a minimum, include otoscopy, tympanometry, ipsilateral and contralateral acoustic reflex thresholds (ARTs), otoacoustic emissions (OAEs), puretone air and bone conduction thresholds, speech recognition thresholds (SRTs), and word recognition tests administered in an acoustically controlled environment (i.e. sound booth) (AAA, 2010). A comprehensive audiological evaluation is completed to rule out a conductive or sensorineural hearing loss (Keith, 2004; Rosen et al., 2010). If there are any red flags for other auditory disorders, further testing to rule out suspected disorders is recommended prior to the administration of the APD test battery. A comprehensive audiologic evaluation will give the audiologist a more complete picture of peripheral auditory system function prior to additional testing.

Ruling out auditory neuropathy spectrum disorder (ANSD).

One auditory disorder that may have a similar profile to APD and needs to be ruled out is auditory neuropathy spectrum disorder (ANSD) (Jerger & Musiek, 2000; Keith, 1999). ANSD is characterized by normally functioning outer hair cells (OHCs) and dysfunction of the inner hair cells (IHCs) in the cochlea, a faulty connection between the IHCs and the VIIIth (auditory) nerve, or dys-synchronous neural firing of the VIIIth nerve (Jerger & Musiek, 2000; Norrix & Velenovsky, 2014). According to Norrix and Velenovsky (2014), a typical profile of ANSD is present otoacoustic emissions (OAEs), absent acoustic reflex thresholds (ARTs), varying pure tone thresholds (normal to profound hearing loss), varying word recognition scores (WRSs), and poor performance on speech in noise tests. When the behavioral test results indicate ANSD, an auditory brainstem response (ABR) test (usually modified to include a comparison of compression and rarefaction stimuli) is performed to confirm the diagnosis. An ABR is a neural response that measures the integrity of the VIIIth nerve and the brainstem (Picton, 2011). If the response is normal, the APD test battery is administered, if the response is abnormal and ANSD is confirmed, the APD test battery is not administered (Jerger & Musiek, 2000; Norrix & Velenonsky, 2014)

Patient selection criteria and confounding factors.

The APD test battery is administered after the audiologist confirms hearing to be within normal limits. With the test battery approach, the audiologist assesses the integrity of various abilities of the auditory system and conducts a differential diagnosis for APD (AAA, 2011; ASHA, 2005). It is imperative that the patient fit the requirements for APD testing or it is likely that auditory disorders, such as hearing loss or ANSD, will affect the results of the tests (AAA, 2010). Factors such as developmental age, cognitive status, language ability, native language, attention, fatigue, and motivation can also affect the results of the test battery (Jerger & Musiek, 2000; Rosen et al., 2010). All of these factors need to be considered for each patient and addressed on an individual basis (i.e., test selection, shorter test time for fatigue and motivation, if English is the second language) (AAA, 2010; Jerger & Musiek, 2000; Rosen et al., 2010).

Developmental Age.

The youngest suggested age for an APD evaluation is 7 years, 0 months (AAA, 2010; ASHA, 2005; Jerger & Musiek, 2000). Although there are AP tests available for children younger than 7 years, 0 months, there are very few tests with normative data available (AAA, 2010; Jerger & Musiek, 2000). According to AAA (2010), reasons for this include: lack of maturation of the central auditory nervous system (CANS), lack of ability to understand and follow test directions, ceiling effects, and potentially unreliable test results. These reasons can make administering AP tests and interpreting the results difficult. AP tests developed for children younger than 7 years of age (i.e., SCAN-3:C Tests for Auditory Processing Disorders in Children, Pediatric Speech Intelligibility Test, and the Staggered Spondaic Word Test), are only used to evaluate children under 7 years who are suspected of having APD and a comprehensive diagnostic APD evaluation should be performed when the child turns 7 years of age (AAA, 2010; Jerger & Musiek, 2000).

The audiologist must also consider the patient's developmental age, or cognitive function, before administering the AP test battery (AAA, 2010). Developmental age takes the patient's cognitive status into consideration. This can affect memory, attention, and comprehension of test instructions (Ferguson, Hall, Riley, & Moore, 2011; Sharma et al., 2009). Although a patient may be chronologically older than 7,0 years, s/he may function cognitively at an age level <7,0 years. The audiologist should be able to determine if there is an underlying general cognitive deficit apart from auditory difficulties identified through administration of screening tests (Moore et al., 2010; Rosen et al., 2010). Even if the patient is capable of completing the AP test battery, test modifications need to be considered (i.e., more testing time) (AAA, 2010). If the audiologist decides to discontinue the testing, an appropriate referral to another professional should be considered (i.e., educational psychologist, developmental pediatrician) (AAA, 2010; Rosen et al., 2010).

Language.

Language can also be factor that interferes with accurate interpretation of APD test results (AAA, 2010; Hooi Yin Loo et al., 2013; Sharma et al., 2009). An LI or English as a second language (ESL) can cause the patient to misinterpret the instructions and/or the audiologist to misinterpret the patient's responses (Dawes & Bishop, 2009; Hooi Yin Loo et al., 2013). To avoid misinterpretation, an APD test battery that is not heavily language loaded is recommended (AAA, 2010; Ferguson et al., 2011; Hooi Yin Loo et al., 2013). However, tests that have some language component may be unavoidable because they are needed for the development of a core battery or may be selected to assess a patient complaint's specific complaint (i.e. sentences in noise) (AAA, 2010). . Patients who appear to have limited language or are suspected of a language delay should be referred to an SLP for a full evaluation that includes phonological processing before the APD battery is administered (Dawes & Bishop, 2009; Witton, 2010).

ESL can also affect the results of the AP test battery. Patients not proficient in English may lack sufficient language skills to provide appropriate responses to test items; this could result in failure of the test with individuals who do not have APD (Hooi Yin Loo et al., 2013). Crandell and Smaldino (1996) compared speech perception in noise of 20 native English speakers and 20 ESL speakers. They found the ESL participants showed more difficulty with identifying English words in adverse listening environments; this is possibly due to limited language knowledge of their second language (Crandell & Smaldino, 1996).

According to Hooi Yin Loo et al. (2013), decreased AP scores could be a result of APD or insufficient language knowledge. They compared the performance of native English speakers (*n* = 71) and ESL speakers (*n* = 133) on AP tasks (Hooi Yin Loo et al., 2013). Results showed no significant difference between the two groups on non-speech AP tests, but did show that native English speakers performed better on AP tests with speech stimuli or verbal responses than ESL speakers (Hooi Yin Loo et al., 2013). In order to avoid such issues, an APD test battery mainly consisting of non-speech stimuli is ideal (AAA, 2010; Hooi Yin Loo et al., 2013).

Motivation.

Motivation can also affect test validity and reliability and may need to be addressed several times throughout the appointment (ASHA, 2005; Silman, Silverman, & Emmer, 2000). Constant reinforcement keeps children on track for each task, and providing snacks and/or small prizes motivates children to participate (Silman et al., 2000). Since reinforcement has shown to be successful in obtaining reliable results for pediatric audiologic evaluations, Silman et al. (2000) assessed previously diagnosed children (*n* = 3) with APD under two conditions: reinforcement with food or favorite toys versus no reinforcement. All three children had scores below the normal range for all tests administered in the no reinforcement condition (Silman et al., 2000). When the children were re-tested three weeks later under the reinforcement condition, Silman et al. (2000) found a marked improvement in test scores. The improved scores, which were in the normal range for two children and near normal for the third child, indicated that motivation should be accounted for when administering an APD test battery (Silman et al., 2000).

Attention and fatigue.

In addition to lack of motivation, young children typically have a shorter attention span than adults and tend to fatigue more easily. The audiologist should select an AP test battery that can be completed within 45-60 minutes when assessing children suspected of APD (AAA, 2010). It is also necessary to provide periodic breaks if test sessions exceed 1 hour (AAA, 2010; ASHA, 2005). If a child has a diagnosed attention disorder (ADHD), it is imperative that s/he takes his/her prescribed medication on test days in order to avoid invalid results or the test cannot be administered at that appointment (ASHA, 2005). If there is a persistent attention concern that cannot be corrected with periodic breaks or currently prescribed medication, a referral for an assessment by an ADHD specialist should be given before continuing with the APD test battery (ASHA, 2005).

The APD Test Battery

Although there are recommendations for putting together an AP test battery, a universal test battery does not exist to date (AAA, 2010; ASHA, 2005; BSA, 2011; Iliadou & Bamiou, 2012; Musiek et al., 2005; Musiek et al., 2011). A universal test battery will likely never exist, due to the differences that need to be considered for patients suspected of having APD (Musiek et al., 2005). Musiek et al. (2005) recommend that audiologists follow the established guidelines (AAA, 2010; ASHA, 2005) that allow for test selection on a case by case basis when compiling an APD test battery. Most test batteries include at least one test from the following domains: MLR, DL, and TP (Bellis & Ferre, 1999; Keith, 1999; Musiek et al., 2011). According to a survey by Emanuel et al. (2011), the majority of audiologists with APD experience reportedly use tests from each of these domains. A more recent test that is finding its way into the APD test battery is the listening in spatial noise sentences test (LiSN-S) that assesses sound localization and lateralization abilities (Cameron & Dillon, 2006; Hall, 2007). The LiSN-S requires the listener to use localization cues to identify the signal that is embedded in competing noise from various angles (Cameron, Dillon, & Newall, 2006; Cameron & Dillon, 2007a; Cameron & Dillon, 2008). Tests that are used to diagnose APD must have normative data on typically developing, age-appropriate controls with normal hearing, normal IQ, and are gender balanced (AAA, 2010; ASHA, 2005; Brown, Sherbenou, & Johnsen, 1997).

Types of behavioral tests.

Monaural low redundancy (MLR).

MLR tasks use a speech signal that is degraded or altered in frequency, intensity, and/or time, making the signal more difficult to understand (AAA, 2010; ASHA, 2005; Bellis & Ferre, 1999; Krishnamurti, 2009). By manipulating speech to sound “quick” or “muffled,” or by adding competing noise, the audiologist can assess the listener’s ability to use the remaining cues of the signal to achieve auditory closure when the auditory signal is unclear (AAA, 2010; Bellis & Ferre, 1999). Listeners without APD have the ability to “fill in the blanks” when parts of the signal are missing (O’Beirne, McGaffin, & Rickard, 2012, p. 778). Spoken language is highly redundant, but when acoustic redundancy is eliminated, those with AP difficulties are unable to achieve auditory closure (O’Beirne et al., 2012).

Time Compressed (45%) plus Reverberation (0.3s) Speech Test.

Time compressed and reverberated words (CRW) measure patients’ ability to process quick alterations to incoming auditory signals (Wilson, Preece, Salamin, Sperry, & Bornstein, 1994). This test includes 25 words from the NU-6 word list that have been compressed by 45% (45% of the original signal has been eliminated) and includes a reverberation or “echo” time of 0.3 seconds to each ear separately (Wilson et al., 1994). This is a standardized test, and cut-off scores are provided by age.

Auditory Figure Ground (AFG).

Auditory figure ground (AFG) measure patients’ ability to separate the signal from the competing noise (Keith, 2009). This test includes 20 words in the right ear (test ear) followed by 20 words in the left ear (test ear) while simultaneously presenting multi-talker babble (noise) into the test ear (Keith, 2009). There are three signal to noise ratios (SNRs) to choose from: +12 dB (the signal is 12 dB greater than the competing noise), +8 dB (the signal is 8 dB greater than the competing noise), and 0 dB (the signal is at the same loudness level as the competing noise) (Keith, 2009).

Dichotic listening (DL).

Tests of DL present a different acoustic signal to each ear simultaneously (AAA, 2010; ASHA, 2005; Keith, 1999; Noffsinger, Martinez, & Wilson, 1994). Some dichotic tasks require patients’ attention to be focused on each signal presented to the right and left ear (integration), while other dichotic tasks require separated attention and focus on only the signal presented to a specified ear (separation) (Keith & Anderson, 2009). By presenting a signal simultaneously, dichotic listening tasks measure patients’ ability to integrate or separate competing auditory information (Keith & Anderson, 2009). Acoustic stimuli for dichotic tasks include digits, consonant-vowel syllables, monosyllabic words, spondees (two syllable words), and sentences (Keith, 1999; Noffsinger et al., 1994). It is normal for dichotic listening tasks to result in a right ear advantage (i.e., a higher score for correct items identified for the right ear than the left ear) for children under the age of

12 (Noffsinger et al., 1994). The information entering the right ear travels directly to the language area of the brain (left temporal lobe for the majority of listeners), whereas the information entering the left ear has a longer route to reach the language dominant hemisphere, which results in a right ear advantage (Noffsinger et al., 1994). The pathways of the CANS are still developing, specifically the corpus callosum, until about 10-12 years of age, when they reach full maturation (Noffsinger et al., 1994). However, an ear advantage, either right or left, is atypical for patients 12 years and older (Musiek, 1983; Noffsinger et al., 1994).

Dichotic Double Digits Test (DDT).

The dichotic double digits test (DDT), developed by Frank Musiek, measure patients' ability to integrate the auditory signal heard in both ears. This test includes a set of 20 two-digit pairs to the right ear while simultaneously presenting a different set of 20 two-digit pairs to the left ear (Musiek, 1983). The patient is instructed to repeat all four numbers that were heard. The digits include numbers 1-6 and 8-10; the number 7 is excluded because it is a two-syllable number (Musiek, 1983). This is a standardized test; cut-off scores are provided by age and by ear.

Temporal processing (TP).

TP tasks measure patients' ability to process an acoustic signal in a specified time domain (Bellis & Ferre, 1999; Phillips, 1999). According to Moore (1989), some temporal patterning tasks measure patients' ability to process two or more signals and identify a pattern that is either frequency or duration specific (known as temporal ordering or sequencing), while some temporal processing tasks measure patients' ability to identify the shortest interval of time between two acoustic signals (known as temporal resolution or discrimination) (as cited in Phillips, 1999, p. 344).

Frequency Pattern Test (FPT).

The frequency pattern test (FPT) measure patients' temporal sequencing ability related to frequency (Shinn, 2009). This specific test includes a set number of patterns of three tones that vary by a low frequency (e.g., 880 Hz) and a high frequency (e.g., 1430 Hz) to each ear separately (Musiek, 1994). Each pattern consists of two tones of the same frequency and one tone of a different frequency. The patient is instructed to repeat the pattern that was heard by identifying the tones as "low" or "high". For example, a possible sequence is: high-high-low (Musiek, 1994). This is a standardized test with good sensitivity and specificity (Musiek, 1994). Cut-off scores are provided by age (Musiek, 1994).

Duration Pattern Test (DPT).

The duration pattern test (DPT) measure patients' temporal sequencing ability related to duration (Shinn, 2009). This specific test includes a set number of patterns of three tones (1000 Hz) that vary by a short duration (250 msec.) and a long duration (500 msec.) to each ear separately (Musiek, 1994). Each pattern consists of two tones of the same duration and one tone of a different duration. The patient is instructed to repeat the pattern that was heard by identifying the tones as "short" or "long". For example, a possible sequence is: long-long-short (Musiek, 1994). This is a standardized test with good sensitivity and specificity. Cut-off scores are provided by age (Musiek, 1994).

Random Gap Detection Test (RGDT).

The random gap detection test (RGDT) measure patients' temporal resolution ability (Shinn, 2009). This specific test includes a series of tones that sound similar to a "rain drop". The tones are separated by intervals of 2, 5, 10, 15, 20, 25, 30, and 40 msec. or have no interval (0 msec.) (Keith, 2000). The patient is instructed to state if s/he heard one tone or two tones. There are four subtests that consist of 500, 1000, 2000, and 4000 Hz tones. The shortest interval that is identified by the patient is his/her threshold for that specific frequency. An average threshold is calculated by averaging the thresholds of all four test frequencies (Keith, 2000). This is a standardized test, and there is a cut-off score of <20 msec. for all ages (scores ≥20 msec. are considered to be abnormal) (Keith, 2000).

Sound localization and lateralization.

Sounds occur in various locations within our auditory space. The ability to sort through incoming auditory information and separate competing noise from the desired signal by using localization cues is binaural processing, or spatial hearing (Cameron et al., 2006). The Listening in Spatialized Noise (LiSN) Test measure patients' ability to separate sounds occurring in one direction from sounds occurring in another direction (i.e. spatial figure ground) (Cameron et al., 2006; Cameron & Dillon, 2007b; Cameron & Dillion, 2008; Cameron et al., 2009; Cameron, Glyde, & Dillon, 2011).

Listening in Spatialized Noise- Sentences Test (LiSN-S).

The LiSN-S test measure patients' SRT for target sentences in a three-dimensional sound space in the presence of competing noise (i.e. children's stories) (Cameron & Dillion, 2009). The patient is instructed to repeat target sentences that are delivered at 0 degrees azimuth with competing noise occurring at 0 degrees, +90 degrees, and/or -90 degrees azimuth (Cameron & Dillon, 2007b; Cameron & Dillon, 2009). The same speaker delivers the target sentences and competing stories for some tasks, while different speakers are used for the target sentences and competing stories on other tasks (Cameron & Dillon, 2008). This is a standardized test for patients six years of age and older with scores based on age appropriate normative data (Cameron & Dillon, 2007b; Cameron & Dillon, 2009; Cameron et al., 2011).

Sensitivity and specificity.

It is the audiologist's responsibility to choose appropriate tests that have high sensitivity and high specificity in order to reduce "diagnostic error" (AAA, 2010; CISG, 2012; Musiek et al., 2005; Musiek et al., 2011). Sensitivity is the test's ability to correctly identify those with the disorder, while specificity is the test's ability to correctly classify those without the disorder as normal (AAA, 2010; CISG, 2012). Validity is the test's accuracy relative to what the test is intended to measure, and reliability refers to consistency of test scores when testing is repeated (AAA, 2010). A test with high sensitivity and low specificity can lead to over-diagnosis of the disorder, whereas high specificity and low sensitivity can lead to under-diagnosis of the disorder (Bellis, 2003; Jerger & Musiek, 2000). Test efficiency is considered to be a combination of both sensitivity and specificity (ASHA, 2005).

Some tests used for APD are relatively balanced with good sensitivity and specificity; however, there are some tests that are not (AAA, 2010; Musiek et al., 2011). Musiek et al. (2011) tested 49 participants, 20 with known neurologic lesions and a control group of 29 participants with no known neurologic lesions. DDT, FPT, filtered speech and competing sentences made up the APD test battery (Musiek et al., 2011). The

FPT yielded the highest efficiency using the Dartmouth-Hitchcock Medical Center (DHMC) and DHMC+1 cutoffs (90% and 94%), respectively, followed by competing sentences (90% and 90%), DDT (86% and 88%), and filtered speech (63% and 65%) (Musiek et al., 2011). Musiek et al. (2011) also found that pairing the FPT with the competing sentences test yielded even higher test efficiency (92%) than either test when individually administered. However, this was not the case for every combination of tests (i.e. competing sentences and filtered speech, etc.), nor was it the case when increasing the number of tests used for an APD test battery (Musiek et al, 2011). Audiologists need to be able to choose the most appropriate test combination(s) that provide high sensitivity, specificity and efficacy and an accurate diagnosis of APD (Musiek et al., 2011).

Diagnosing APD

Auditory processing is a disorder affecting the auditory system. An audiologist who is properly trained in the diagnosis and treatment of APD diagnoses the disorder (AAA, 2010; ASHA, 2005).

Diagnostic criteria that are universally agreed upon to confirm the presence of APD must be established (Bellis, 2003; Wilson & Arnott, 2013). More specifically, definitions and guidelines that consider patient performance abnormal must be determined for each individual test, as well as for the diagnostic test battery as a whole (Dawes & Bishop, 2009; Wilson & Arnott, 2013). Cut off values establishing the borders of normal limits for each test and the overall test battery are determined based on the performance level of normal hearing individuals without APD. Normative data are collected on a large sample of people without APD who have normal hearing, IQ level, and language ability (AAA, 2010; ASHA 2005; Keith, 1999). At present, the criteria to diagnose APD is as follows: a score of two standard deviations (SDs) or more below the mean for at least one ear on at least two different tests in the APD battery, or when performance on one test is three SDs or more below the mean (AAA, 2010; ASHA, 2005; Chermak & Musiek, 1997). ASHA (2005) suggested that if only one test shows extremely poor performance (i.e. 3 SDs or below), the test should be re-administered along with another test that assesses the same auditory process, in order to verify that a processing disorder does exist.

Importance of a differential diagnosis.

The diagnosis of APD is complicated by co-occurring disorders that present similarly to APD (AAA, 2010; ASHA 2005; Dawes & Bishop, 2009; Jerger & Musiek, 2000; Keith, 1999; Sharma et al., 2009). Similar presenting symptoms may make it difficult to identify which professional the child should be referred to for a diagnostic assessment (Ferguson et al., 2011). It is known that APD can occur in pure form in an individual (4%; Sharma et al., 2009), although rare, or co-occur with other disorders (Cacace & McFarland; Musiek et al., 2005;Witton, 2010).

The brain operates as a multimodal system, with each part of the brain performing a specific function but receiving contributions from various adjacent areas (Musiek et al., 2005). This can make the symptomology for multiple disorders appear similarly, making it difficult for the person referring the child for assessment to identify which professional should asses the child first (Ferguson et al., 2011; Dawes & Bishop, 2009). There may also be outside factors affecting brain based processing more globally (Witton, 2010). Due to the possible co-morbidity of APD and other disorders, a process to assist with differential diagnosis is suggested for all APD referrals. This will help identify potential co-occurring disorders and assist with the development of appropriate recommendations (Witton, 2010). While an interdisciplinary team would be ideal, they are not always feasible; therefore, additional steps should be taken by audiologists to ensure accurate diagnoses are made (Witton, 2010).

Co-Occurring Disorders with APD

Screeners for co-occurring disorders.

It is important for the audiologist to be familiar with disorders that co-occur with APD. Audiologists need to know the effects of language, memory, cognition, and behavior on AP test results to accurately assess children for APD. It is also important that audiologists are familiar with screening tests for disorders that co-occur with APD so that when a full diagnostic evaluation cannot be performed, the audiologist can, at a minimum, screen for those disorders (e.g. LI, ADHD, cognitive delays). Disorders that affect attention (i.e. ADHD), language (i.e. expressive or receptive language disorder, phonological processing), reading (i.e. dyslexia, phonological processing), and/or learning typically present with similar symptoms as APD and often cause similar difficulties with communication (ASHA, 2005; Chermak, Tucker, & Seikel, 2002; Keith, 2004; Sharma et al., 2009). It is important for the audiologist to recognize similarly presenting disorders to avoid a misdiagnosis, understand how to properly administer and interpret the screening tests, and collaborate with professionals who diagnose and treat the co-occurring disorders (Bellis & Ferre, 1999; Witton, 2010).

If a disorder other than APD is suspected, the audiologist should administer a screening test that identifies potential red flags for the suspected disorder and make a referral to the appropriate professional (Bellis, 2003). In cases where APD is suspected, language, attention, reading and/or intelligence is of concern, and a screening test is unavailable, the audiologist should refer the patient to the appropriate professional after completing the audiologic examination, but before conducting APD assessment. This precaution is to ensure that a proper diagnosis has been made (Bellis, 2006; Keith, 2004).

Clinical Evaluation of Language Fundamentals, 4th Edition (CELF-4).

The Clinical Evaluation of Language Fundamentals 4th Ed. (CELF-4) Screening Test is a 47-item screening measure of expressive and receptive language for children 5,0 to 21,11 years of age (Semel, Wiig, & Secord, 2004). It is used to identify children who may be at risk for a language disorder and need to be referred to an SLP for further testing (Semel et al., 2004). It is age dependent: items 1-28 consist of four language tasks administered to children 5,0 to 8,11 years of age, and items 29-47 consist of five language tasks administered to children 9,0 to 21,11 years of age (Semel et al., 2004). The CELF-4 Screening Test is not a comprehensive language evaluation and should not be used to diagnose children with a language disorder. Professionals such as audiologists, teachers, and educational psychologists can administer the CELF-4 Screening Test, but only an SLP administers the CELF-4 Diagnostic Test and diagnoses a language disorder (Semel et al., 2004).

Comprehensive Test of Phonological Processing (C-TOPP).

The CTOPP is a measure that assesses phonological awareness (PA), phonological memory (PM), and rapid naming (RN) (Wagner, Torgesen, & Rashotte, 1999). PA is awareness of individual sounds and the structure within one's oral language (Wagner et al., 1999). PM and RN consist of the ability to code phonological information to store it in short-term memory and to retrieve it from long-term memory, respectively (Wagner et al., 1999). The CTOPP is used to identify a weakness in phonological processing and those “at risk” for a reading disorder (Wagner et al., 1999). It also indicates the need for further testing by an SLP.

Two versions exist and are divided according to age of the patient: one for ages 5 years, 0 months to 6 years, 11 months and one for ages 7 years, 0 months to 24 years, 11 months (Wagner et al., 1999). Subtests of the CTOPP include: Elision, Blending Words, Memory for Digits, Nonword Repetition, Rapid Digit Naming, and Rapid Letter Naming (Wagner et al., 1999). Supplemental tests include: Blending Nonwords, Segmenting Words, Segmenting Nonwords, and Phoneme Reversal (Wagner et al., 1999). Examiners administering the CTOPP should have extensive, formal training on the administration and interpretation of the test (Wagner et al., 1999).

Test of Nonverbal Intelligence 3rd Edition (TONI-3).

The TONI-3 is a 45-item measure of cognitive ability for ages 6,0 to 89,11 years that assesses how people do in a nonverbal environment (Brown et al., 1997). It assesses abstract/figural problem solving skills without the use of language for instruction, the test itself, and responses (Brown et al., 1997). Cognitive ability can then be measured without language influence that would otherwise be compromised in those with a language disorder, a neurological complication, or ESL speakers (Brown et al., 1997).

Test instructions are delivered via nonverbal gestures (i.e. mimed) to the participant and a set of practice items are given to confirm that s/he understand the task. The participant indicates his/her answer from the Picture Book by pointing with a finger, light beam, etc., or through a meaningful gesture such as an eye blink (Brown et al., 1997). The test is terminated when the examiner perceives a scoring ceiling has been reached (Brown et al., 1997). Audiologists, educational psychologists, teachers, SLPs, and other qualified professionals who are trained, have experience with, and follow the exact directions of the TONI-3 manual can administer the test (Brown et al., 1997). The TONI-3 is typically administered in conjunction with other pre-screeners (i.e. CELF-4 Screening Test) so that proper recommendations can be made for further testing if needed. Significantly low scores (<85) suggest cognitive disorders, while significantly high scores (>115) suggest intellectual giftedness (Brown et al., 1997). Results must be interpreted carefully (Brown et al., 1997).

Integrated Visual and Auditory Continuous Performance Test (IVA-CPT).

BrainTrain Integrated Visual and Auditory Continuous Performance Test (IVA-CPT) is a computer-based test that measures auditory and visual impulsivity and attention in people 5 to 90 years of age (Sandford & Turner, 1999). A randomized pattern of 1s and 2s are presented as 500 trials separated by 1.5 seconds to the participant through the auditory or visual modality (Sandford & Turner, 1999). The participant responds by clicking a mouse only when s/he sees or hears the target number (i.e. “1”) (Sandford & Turner, 1999). Four categories are measured: Attention, Response Control, Attribute, and Symptomatic (Sandford & Turner, 1999). BrainTrain IVA-CPT was used as a pre-screener for sustained attention ability to indicate if a referral to another professional is needed. Only a mental health professional that specializes in ADHD is qualified to diagnose the disorder. Screening tests such as the IVA-CPT assist other professionals in identifying people “at risk” for attention disorders.

Co-occurring disorders.

There are several disorders that can impact test results or the tester's ability to accurately assess for APD; therefore, screening tests are often administered to assist in test selection for the APD battery and/or recommendations. While some disorders can co-exist with APD, it should be noted that there is no known causal relationship between APD and any disorder (i.e. APD is not a result of ADHD, LI, phonological processing disorders, RD, LD, and/or cognitive disorders) (AAA, 2010; ASHA, 2005; Chermak et al., 2002; Sharma et al., 2009; Witton, 2010). While these co-occurring disorders display similar symptoms to APD, a differential diagnosis is highly recommended in order to identify the specific disorder(s) in question (Ferguson et al., 2011; Witton, 2010).

Attention-Deficit/Hyperactivity Disorder (ADHD).

According to the *Diagnostic and Statistical Manual of Mental Disorders (DSM-V)* ADHD is a neurodevelopmental disorder that typically appears during development and mainly prior to entering elementary school (APA, 2014). It is "a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development" (APA, 2014, p. 59). Inattention refers to difficulty focusing that is not due to a lack of understanding (APA, 2014). Hyperactivity is extreme movement when it is unnecessary or inappropriate (i.e. fidgeting, talking, etc.) (APA, 2014; Chermak et al., 1999). Impulsivity is making careless decisions without properly thinking through the potential consequences; impulsiveness may lead to poor decisions or harmful behaviors (APA, 2014).

A diagnosis of ADHD for a child requires that several inattentive or hyperactive-impulsive symptoms must be present before 12 years of age, have persisted for at least six months, and are present in two or more settings (i.e. home, school, activities, etc.). These symptoms (Table 1) must show that they prevent normal and appropriate social, academic, or occupational functioning, and are not a result of schizophrenia, another psychotic disorder, or a mental disorder (APA, 2014). According to a population survey, ADHD occurs in about 5% of children in most cultures, and is more common in males than females (2:1) (APA, 2014). ADHD is diagnosed by a pediatrician who specializes in mental health, and can be treated with medication, psychotherapy, education and/or training (Chermak, Somers, & Seikel, 1998).

ADHD does not have a biomarker for diagnosis (Chermak et al., 1999). It is diagnosed based on presenting symptoms, which can be similar to the symptoms of APD (APA, 2014; Chermak et al., 1998; Chermak et al., 2002). Due to this overlap of symptoms, it was questioned whether or not APD and ADHD were two separate disorders, or if APD occurred as a result of ADHD (Chermak et al., 1999; Chermak et al., 2002). APD is a sensory perceptual and input disorder that is specific to deficits in the processing of incoming auditory information (Chermak et al., 1999; Chermak et al., 2002). ADHD is considered to be a cognitive and output disorder with deficits in processing across various modalities (Chermak et al., 1999; Chermak et al., 2002). It is also now considered a disorder of self-control and behavioral regulation instead of an attention disorder, further differentiating it from APD (Chermak et al., 1999; Chermak et al., 2002).

Table 1

DSM-V Criteria for Diagnosis of ADHD Subtypes

Inattention

1. Poor attention to detail
2. Difficulty sustaining attention
3. Does not listen when directly spoken to
4. Does not finish tasks- easily side-tracked
5. Difficulty organizing tasks and activities
6. Difficulty with tasks that require sustained mental effort
7. Often misplaces things
8. Easily distracted
9. Forgetful in daily activities

Hyperactivity-Impulsivity

1. Fidgets, squirms around, or taps hands or feet
2. Leaves seat when supposed to remain in seat
3. Climbs or runs in inappropriate situations
4. Difficulty with staying quiet during leisure activities
5. Always "on the go"
6. Talks excessively
7. Blurts out responses
8. Difficulty waiting his/her turn
9. Often interrupts others

Note. Table created from DSM-V diagnostic criteria for ADHD (APA, 2014).

There are three subtypes of ADHD that must present with their designated symptoms for at least six months or more: combined presentation (ADHD-C), predominantly inattentive presentation (ADHD-PI), and predominantly hyperactive/impulsive presentation (ADHD-HI) (APA, 2014; Chermak et al., 2002). ADHD-C presents with behavioral symptoms of both inattention and hyperactivity-impulsivity, ADHD-PI presents with behavioral symptoms of inattention, but not hyperactivity-impulsivity, and ADHD-HI presents with behavioral symptoms of hyperactivity-impulsivity, but not inattention (APA, 2014; Chermak et al., 2002).

In order to determine if there are behavioral symptoms that distinguish APD from ADHD, Chermak et al. (1998) compared the rankings of commonly occurring symptoms provided by audiologists and pediatricians, respectively. Results were generated from 81 surveys (33 audiologists; 48 pediatricians), which listed 41 behavioral symptoms typically associated with APD and ADHD to be rated via a rating scale (1: never observed; 5: always observed). Of the 41 symptoms, a list of six common symptoms for ADHD and a list of seven common symptoms for APD were composed and compared (Table 2). Two common symptoms, inattention and distractibility, were a part of both lists. Inattention and distractibility ranked first and second, respectively, for ADHD, and seventh and sixth, respectively, for APD. However, nine symptoms were found to distinguish between the two disorders. These nine distinguishing symptoms can be used as supplemental information when screening for APD or ADHD and when referring to the appropriate professional (Chermak et al., 1998).

Table 2

Rank Order of Behavioral Means

ADHD	CAPD
1. Inattentive	1. Difficulty hearing in background noise
2. Distracted	2. Difficulty following oral instructions
3. Hyperactive	3. Poor listening skills
4. Fidgety or restless	4. Academic difficulties
5. Hasty or impulsive	5. Poor auditory association skills
6. Interrupts or intrudes	6. Distracted
	7. Inattentive

Note. From "Behavioral Signs of Central Auditory Processing Disorder and Attention Deficit Hyperactivity Disorder," by G. D. Chermak, E. K. Somers and J. A. Siekel, 1998, *Journal of the American Academy of Audiology, 9,* p. 80. Reprinted without permission.

Chermak et al. (2002) repeated the Chermak et al. (1998) study, but compared a subtype of ADHD (i.e. ADHD-PI) that is considered to be the most similar of the subtypes to APD. Chermak et al. (2002) added 17 more behavioral symptoms to the original list with the same rating scale as the 1998 study, but also included the option of “don’t know”. Results were generated from 49 surveys (26 audiologists; 23 pediatricians), and a list of nine typical symptoms of ADHD and a list of twelve typical symptoms of APD were composed and compared. Of the fifteen symptoms listed, six were shared between APD and ADHD: asks for things to be repeated, poor listening skills, difficulty hearing in background/ambient noise, academic difficulties, distracted, and auditory divided attention deficit (Chermak et al., 2002). Similar to the previous study’s results, more behaviors (nine) were found to be unique to APD or ADHD-PI than shared between the two disorders (Chermak et al., 2002). These distinguishing symptoms are considered to be exclusive to either APD or ADHD-PI and further distinguish APD and ADHD-PI as two separate disorders (Chermak et al., 2002).

Language Impairment (LI).

According to the *Diagnostic and Statistical Manual of Mental Disorders (DSM-V)*, a language disorder is a neurodevelopmental disorder that appears during early development (APA, 2014). LI causes difficulty with the development and/or use of language in all forms (i.e., spoken, written, sign language, or other) (APA, 2014). Those with LI experience difficulty with understanding incoming language (receptive), and/or language production (expressive). They tend to have reduced vocabulary, limited sentence structure, and impairments in discourse (APA, 2014). Language is significantly reduced in comparison to peers with typically developing language, and is not a result of hearing loss, other sensory impairments, medical conditions, or a global developmental delay. A language disorder may affect communication, academic achievement, social interactions, and occupation (APA, 2014).

An SLP diagnoses a language disorder after a comprehensive case history, observation of language samples, and interpretation of standardized tests of language ability (APA, 2014). Although language disorders can co-occur with APD, researchers have questioned if a true co-occurrence is possible (Dawes & Bishop, 2009; Sharma et al., 2009). Sharma et al. (2009) tested for co-occurrence of multiple disorders in 68 children 7-12 years of age with suspected or diagnosed APD. Some children had a diagnosis of APD only (*n* = 9), reading disorder only (*n* = 20), or other diagnoses (*n* = 10) (i.e. ADHD, dyspraxia, etc.). Ten children had no formal diagnosis at all. The children completed test batteries for APD, language, hearing, and psycho-education. A diagnosis of APD, language impairment (LI), and/or reading disorder (RD) was made based on the results. Of the 68 children, 32 were diagnosed with all three disorders, eight with LI and RD, seven with APD and LI, seven with APD and RD, five with LI, three with APD, three with RD, and three who passed the entire AP test battery. Results indicated that APD co-occurred with close to 50% of the children. The high rate of co-occurring disorders highlights the importance of a differential diagnosis (Sharma et al., 2009).

Studies have indicated LI and APD may be interchangeably diagnosed depending on the professional who first evaluates the child (Ferguson et al., 2011). Both disorders have similarly presenting symptoms and difficulties, which require a multidisciplinary team to accurately diagnose and treat the disorder(s) (Ferguson et al., 2011; Sharma et al., 2009). Ferguson et al. (2011) compared 88 children 6 to 13 years of age with specific language impairment (SLI) (n = 22), APD (n = 19) and a random sample of mainstream (MS) school children (n = 47) on the basis of hearing, language, reading, memory and intelligence. Results showed that children previously diagnosed with APD and SLI shared similar scores for a majority of the tests, and scored significantly below the MS population (Ferguson et al., 2011). Although there were slight variations amongst the test results of children with APD and SLI, both disorders had common symptoms and difficulties, low scores on the test battery, and similar parental concerns that still suggest that the diagnosis of APD or SLI highly depends on the referral route if the diagnosing professional does not include pre-screeners that indicate the possibility of a separate or co-occurring disorder (Ferguson et al., 2011).

Phonological processing and reading disorder (RD).

According to Wagner et al. (1999), phonemes are speech sounds strung together to form words, and are used to process both spoken and written language. This process is referred to as phonological processing, which is in close connection to the development of reading skills (Dawes & Bishop, 2009; Ferguson et al., 2011; Sharma et al., 2009; Wagner et al., 1999). Some people who experience difficulty with phonological processing also have a reading disability (RD); most RDs cause difficulty with decoding words phonetically (Wagner et al., 1999).

Auditory processing difficulties are found in children with phonological processing and reading disorders (Bretherton & Holmes, 2003). However, auditory processing deficits do not cause a phonological processing disorder or RD, they co-exist (Sharma et al., 2009). As previously mentioned, Sharma et al. (2009) tested 68 children previously diagnosed with APD, LI, and/or RD on hearing, language and reading screening tests to assess the likelihood of disorders co-occurring with APD. They found that only 11 of the children (15%) appeared to have either "pure" APD, LI, or RD, while the other children (85%) had a combination of two or three of the disorders (Sharma et al., 2009).

Learning disability (LD).

According to the *Diagnostic and Statistical Manual of Mental Disorders (DSM-V)* a learning disability (LD) is poor [academic] achievement despite normal or high intelligence and chronological age. LDs are typically identified in the early school years and are diagnosed by administering a standardized test or by a documented history of significant learning difficulties (for persons under 17 years of age only) (APA, 2014). It affects 5 to 15% of school-aged children and is more common in males than females (2:1 to 3:1) (APA, 2014). Persons with LD can have difficulty in any of the following areas: mathematics, reading, writing, and spelling (APA, 2014). LDs are not a result of poor vision and/or hearing, intellectual disability or other neurological or developmental disorders (APA, 2014). Severity ranges from a mild disability to a severe disability (APA, 2014). LD can co-occur with other disorders, which requires a differential diagnosis (APA, 2014; Iliadou, Bamiou, Kaprinis, Kandyli, & Kaprinis, 2009; Keller, Tillery, & McFadden, 2006).

Iliadou et al. (2009) tested 101 children ranging in age from 8, 0 to 15, 11 years of age with suspected LD for APD. The common symptom between the participants was poor academic achievement (Iliadou et al., 2009). The APD test battery consisted of the speech in babble test, DDT, FPT, DPT, RGDT, and masking level difference (Iliadou et al., 2009). Results showed that 43.3% of the participants were diagnosed with APD in addition to LD; of those diagnosed with APD, 25% had dyslexia (Iliadou et al., 2009). Although Iliadou et al. (2009)'s study is the reverse of this study (advocating for pre-screeners of APD when diagnosis LD), results show that APD and LD can co-occur and highlight the need for pre-screeners for an accurate diagnosis.

Similarly, Keller et al. (2006) determined the prevalence of APD in 18 children (mean age = 10.4 years) with nonverbal learning disability (NVLD). The APD test battery consisted of staggered spondaic words test, phonemic synthesis, and speech-in-noise tests (Keller et al., 2006). Results showed that 61% of the participants (*n* = 18) were diagnosed with APD in addition to NVLD, which again highlights the need for pre-screeners and an interdisciplinary team approach to diagnosis if possible (Keller et al., 2006).

Rationale

Diagnosing APD can be challenging due to possible co-occurring disorders such as ADHD, LI, LD, and RD (AAA, 2010; ASHA, 2005; Ferguson et al., 2011; Jerger & Musiek, 2000; Keith, 1999; Sharma et al., 2009; Witton, 2010). The use of an interdisciplinary or multidisciplinary team is ideal for a differential diagnosis; however, this may not always be a feasible option. Due to known co-occurring disorders in the population suspected of APD or diagnosed with APD, administering screening tests before assessing for APD may aid in ruling out the involvement of other disorder(s). One of the aims of this study was to evaluate the use of several screening tests on populations with suspected or confirmed APD to assist in further profiling children with APD. The addition of other disorders may affect the accuracy of the APD test results and/or assist with appropriate referrals and recommendations. The patient referred for APD testing may have already been evaluated by another professional (or several), however, there are times other disorders are suspected but the patient is seeing an audiologist before other professionals. The use of screening tests prior to evaluating for APD may also provide insight for test selection for the APD battery and can identify if any modifications will be needed to the battery.

A second aim of this study was to evaluate local normative data collected by McDermott (2014) from 120 normal hearing, non-APD children from Maryland and neighboring states on a group of children with confirmed or suspected APD. A core test battery of low-linguistically loaded AP tests that has been developed with normative data from the local population is important to control for such factors as accents (Kelly, 2007). Kelly (2007) tested 129 children in New Zealand that represented their native population to New Zealand. Kelly (2007) also stated that although there is published normative data for each APD test, a majority failed to report the details of their participants (i.e. sample size, age, characteristic of the subject). It is for these reasons that McDermott (2014) collected normative data. It is with this newfound data that this APD test battery was used to complete this project.

Chapter 3

Methodology

Participants

Participants between the ages of 7 years, 0 months to 12 years, 11 months were recruited by performing a thorough retrospective review of patient records at Towson University Hearing & Balance Clinic (TU-HBC), by word of mouth to friends, family, other audiologists, and other related professionals, and through use of a flyer (see Appendix B). Informed consent (parent/guardian) and assent (participant) was obtained from all participants before testing commenced (see Appendix C). Institutional Review Board (IRB) was obtained for this study (see Appendix D).

Equipment and Materials

All testing was performed in the Hearing And Listening Lab (HALL) in Van Bokkelen Hall at Towson University in Towson, MD. The Grason-Stadler (GSI) TympStar Middle Ear Analyzer was used for immittance testing. The ILO version 6.0 Otoacoustic Emissions software was used to obtain otoacoustic emissions (OAEs). The hearing screening and APD test battery was completed in a double-walled, sound-treated booth using a GSI Audiostar Pro audiometer coupled to ER-3A insert earphones. All equipment was within calibration according to ANSI standards.

A Sony 5 CD Changer Disc Ex-change System was used to present the stimuli. The Veteran's Affairs (VA) Tonal/Speech Materials CD Disc 2.0, SCAN-3:C CD, and AUDITEC CD were used to administer the MLR, DL, and TP AP tests. The CDs were calibrated using the respective calibration tones for each CD. All stimuli were presented at 60 dB HL. A Dell Latitude D520 laptop computer was used to administer the LiSN-S using the 4.2 Phonak soundcard via Sennheiser HD 215 headphones. The Dell laptop was also used to present BrainTrain IVA-CPT and the recorded portions of the CTOPP (presented via audio CD).

Procedures

Forms.

Participants' parent/guardian completed a comprehensive case history form (Appendix E) and their teacher(s) completed the LIFE-UK (Appendix F). Supplemental questions were asked, orally, to the parent/guardian for clarification as needed. Teachers were allowed to return the LIFE-UK for data analysis before, during or after the testing was complete.

LIFE-UK.

The teachers' responses to questions 1-11 from the LIFE-UK were used to evaluate the participants' behaviors in the classroom. Each question (1-11) received a point value based on the rating: "very good" (2), "good" (1), "satisfactory" (0), "poor" (-1) or "very poor" (-2). Questions were then categorized into one of the following groups: following directions, attention, involvement in class learning and/or answering questions and rate of learning. Questions from the questionnaire and corresponding category can be seen in Table 3.

Table 3

Questions of the LIFE-UK Categorized by Group

Question	Group
1. Following class directions	Following Directions
2. Following individual directions	Following Directions
3. Overall Attention Span	Attention
4. On task behavior	Attention
5. Rate of learning (speed of following instruction)	Rate of Learning
6. Involvement in class discussions (volunteers more, makes appropriate contributions)	Involvement in Class Learning and/or Answering Questions
7. Contributions when working in a group	Involvement in Class Learning and/or Answering Questions
8. Paying attention to multimedia (e.g. video, OHP)	Attention
9. Willingness to answer questions	Involvement in Class Learning and/or Answering Questions
10. Answering questions in an appropriate and relevant manner	Involvement in Class Learning and/or Answering Questions
11. Amount of repair behavior (this refers to asking questions, to teacher or peer, in order to clarify what is required)	Following Directions

Screening Tests.

The TONI-3, CELF-4 Screening Test, CTOPP, and BrainTrain IVA-CPT were administered prior to completing the audiological screening and APD test battery. The order for administration of the screening tests was randomized for each participant. Randomization for all tests was performed using Random.org, list randomizer.

Test of nonverbal intelligence, 3rd edition (TONI-3).

The TONI-3 was used as a screening test, and administered in a quiet, well-lit room. The examiner used the TONI-3 Picture Book, the Answer and Record Form (Form A and Form B were randomized), and a pen. Administration was done in accordance with the test manual. The TONI-3 was scored in accordance with the test manual.

Clinical evaluation of listening fundamentals, 4th edition- screening test (CELF-4).

The CELF-4 Screening Test was administered in a quiet, well-lit room. Test administration was conducted in accordance with the test manual. Practice items were presented for each task, followed by the actual test items. The test was scored in accordance with the test manual.

Comprehensive test of phonological processing (CTOPP).

Subtests of the CTOPP were used as a screening test, and administered in a quiet, well-lit room. Six subtests were used for this project: Elision, Blending Words, Memory for Digits, Nonword Repetition, Rapid Digit Naming, and Rapid Letter Naming. Test administration was conducted in accordance with the test manual. Practice items were presented for each task, followed by the actual test. Each subtest required different directions and materials (i.e. stopwatch, CTOPP CD, and/or the CTOPP Picture Book), which was further specified in the Examiner's Manual. According to the CTOPP manual interpretation of score ranges were broken into the following categories: "very poor" (35-69), "poor" (70-79), "below average" (80-89), "average" (90-110), "above average" (111-120), "superior" (121-130), and "very superior" (131-165). The subtests were scored in accordance with the test manual.

BrainTrain integrated visual and auditory-continuous performance test (IVA-CPT).

BrainTrain IVA-CPT screened the participants' auditory and visual attention. The examiner filled in the demographic information about the participant before beginning the program. The computer program gave the participant the directions and a practice session prior to beginning the test phase. At the end, the scaled scores were calculated through the computer software program.

Hearing screening.

Otoscopy was completed for both ears, followed by tympanometry and acoustic reflex testing. Tympanometry was performed using a 226 Hz probe tone. Jerger Type tympanograms were recorded. If a participant had a Jerger type B or C tympanogram, they were referred to their physician to provide verification of a "safe" ear before proceeding with the study. Contralateral and ipsilateral acoustic reflex thresholds (ARTs) were tested at 500, 1000 and 2000 Hz bilaterally. ARTs were obtained using routine clinical procedures by starting at 80 dB HL and increasing at 5 dB HL increments until a threshold was found at 0.2 ml and growth in the response was observed.

Transient evoked otoacoustic emissions (TEOAEs) were tested bilaterally at 1000, 1400, 2000, 2800, and 4000 Hz using the ILOv6 to evaluate functioning of the outer cochlear hair cells. TEOAEs were considered present when the signal to noise ratio (SNR) was greater than 3 dB SPL at 1000 Hz and greater than 6 dB SPL from 1400-4000. A pure tone hearing screening was performed at all octaves (250-8000 Hz) at 15 dB HL. Word recognition scores (WRSs) were obtained in each ear separately at 55 dB HL (40 dB SL, re: pure tone screening level of 15 dB HL) using recorded male speech of the Central Institute for the Deaf (CID) W-22 word list (25-words).

APD test battery.

Pass/fail criteria were based on the mean scores and standard deviations of age-appropriate normative data (McDermott, 2014). Due to the length of the research test sessions and complex nature of the participants, the AP tests were re-administered following a break or on a separate day if attention was suspected of interfering (or potentially interfering) with test results. The APD tests were also randomized (order of test administration) and then the first ear assessed for monaurally presented AP tests were randomized. All randomization was conducted using Random.org, list randomizer.

Time compressed (45%) plus reverberation (0.3s) speech test.

The participant heard 25 one-syllable words in the right ear and 25 different one-syllable words in the left ear from the Northwestern University (NU-6) word list. The words were preceded by a carrier phrase, “say the word”. The participant repeated the word that they heard; the CD was paused between each stimulus to allow enough time to respond to the stimulus before the next stimulus was presented. The test was scored separately for each ear. The total number of correct items was divided by 25 and then multiplied by 100 to get the percentage score.

Auditory figure ground (AFG).

Test instructions given in accordance with the test manual. The participant heard one-syllable words under two conditions: an SNR of 0 dB, and of +8 dB embedded in multi-talker babble (i.e. background noise). Two practice items were presented, followed by the actual test items. Twenty words were presented to the first ear followed by twenty words in the second ear. The test was scored separately for each ear and condition. The total number of correct items for each ear were added and converted into a scaled score for each condition using the test manual.

Dichotic digits test (DDT).

Five practice items were presented, followed by the actual test items. The participant heard a set of 20 two-digit pairs to the right ear while simultaneously hearing a different set of 20 two-digit pairs in the left ear. The participant was instructed to repeat all four numbers that were heard. The CD was paused between each stimulus to allow enough time to respond to the stimulus before the next stimulus was presented. Separate scores were calculated for each ear. The total number of correct items were divided by 40 and then multiplied by 100 to get the percentage score.

Frequency pattern test (FPT).

Five practice items were presented, followed by the actual test items. The participant heard 15 patterns of three tones that varied by a low frequency (880 Hz) and a high frequency (1122 Hz) in each ear. Each ear was presented with 15 different patterns and was tested separately. The participant repeated the pattern that was heard by identifying the tones as “low” or “high”. Reversals were considered incorrect responses. The CD was paused between each stimulus to allow enough time to respond to the stimulus before the next stimulus was presented. Separate scores were calculated for each ear. The total number of correct items were divided by 15 and then multiplied by 100 to get the percentage score.

Duration pattern test (DPT).

Five practice items were presented, followed by the actual test items. The participant heard 15 patterns of three 1000 Hz tones that varied by a short duration (250 msec.) and a long duration (500 msec.) in each ear separately. The participant repeated the pattern that was heard by identifying the tones as “short” or “long”. Reversals were considered to be incorrect responses. The CD was paused between each stimulus to allow enough time to respond to the stimulus before the next stimulus was presented. Separate scores were calculated for each ear. The total number of correct items were divided by 15 and then multiplied by 100 to get the percentage score.

Random gap detection test (RGDT).

One practice item was presented, followed by the actual test. Four subtests were administered using 500, 1000, 2000, and 4000 Hz tones. An average threshold was calculated by averaging the threshold of the tested frequencies. The CD was paused between each stimulus to allow enough time to respond to the stimulus before the next stimulus was presented. If the participant did not appear to understand the task, the test stimuli were repeated up to one time per frequency. If the participant had difficulty with one of the four test frequencies, then that frequency was excluded and an average threshold was calculated by using three of the tested frequencies.

Listening in spatialized noise- sentences test (LiSN-S).

The participant heard sentences that were embedded in competing speech. The target sentences were presented at 0 degrees azimuth, while the competing sentences were presented at -90 degrees, 0 degrees, and/or +90 degrees azimuth. The target sentences were initially presented at 62 dB SPL, and varied based on the participant's SRT. The competing noise was presented at 55 dB SPL throughout the test. There were thirty sentences for each of the four conditions (i.e. difference voices at +/- 90 degrees, same voices +/- 90 degrees, different voices at 0 degrees, same voice at 0 degrees). The test was scored by the computer and the following items were recorded: number of reversals, standard error of the mean, SRT, average score for age, client's score, and if the participant scored within normal limits.

Summary Score Sheet

Parent/guardian(s) were given a summary sheet after testing was completed. The summary sheet provided an explanation of the domains assessed and the tests used (screening and AP tests) (see Appendix G). The summary sheet also included a recommendation section that indicated one or more of the following recommendations: test for APD by a licensed audiologist, referral to an appropriate professional for a comprehensive evaluation(s), and no further testing is needed.

Exclusion Criteria

Participants were excluded if: over the age of 12 years, 11 months, under the age of 7 years, 0 months, hearing thresholds >15 dB HL across all of test frequencies, Jerger Type B tympanograms with a small or normal ear canal volume and without patent P.E. tubes or Jerger Type C tympanograms, absent TEOAEs across all test frequencies, absent ipsilateral and/or contralateral ARTs across all test frequencies, and/or a nonverbal IQ score of <80 on the TONI-3.

Data Analysis

Descriptive statistics were used Microsoft Excel for Mac 2011 version 14.3.6 to describe case history information (i.e. birth and otologic history, handedness, and musical instrument), LIFE-UK teacher questionnaire, hearing screening results, screening test results, and APD test results. Participants' scores for the screening and AP tests were compared with 20 age- (+/- 6 months) and gender-matched control group (CG). IBM SPSS Statistic version 21 was used to conduct two-tailed independent t-tests each screening test (dependent variable) and group as the independent variable (SusAPD/APD vs. CG), and for each APD test (dependent variable) and group as the independent variable (SusAPD/APD vs. CG). An alpha value of 0.05 was used to determine significance. If Levene's test indicated that the variances were significantly different and the homogeneity of variances was violated, the test statistic in the row "equal variances not assumed" was used.

Chapter 4

Results

Participants

Eleven children with suspected or previously diagnosed APD (SusAPD/APD) participated in this study. One participant was excluded from data analysis due to a score outside normal limits on the TONI-3. One participant with patent P.E. tubes had a low frequency hearing loss in the left ear, but was cleared by his physician to continue in the study and was therefore included in the data analysis. Data analysis was conducted on 10 participants that included six males and four females. Ages ranged from 8.25 to 12.42 years (M = 10.51, SD = 1.22).

Based on exclusion criteria, participant 007 was excluded from the data analysis due to his results on the screening test measures. Results not only revealed a score <80 on the TONI-3, but scores for CELF-4 Screening Test, IVA-CPT, and the Phonological Awareness subtest of the CTOPP also fell below normal limits. These results reflected his difficulties, which were likely caused by his additional diagnoses of dyslexia, reading disorder (reading was most recently measured at a first grade level), mixed expressive-receptive language delay, and learning disability. Evaluations completed by an educational psychologist, special education teacher, and speech language pathologist also indicated weaknesses in the areas of attention, working memory and processing speed. Although he was diagnosed with these disorders, a speech language pathologist recommended an auditory processing evaluation that was found to be inappropriate.

Case History

Case history information about diagnoses revealed 30% (*n* = 3) of participants had a previous diagnosis of APD. Ninety (90%, *n* = 9) of participants presented with one or more additional diagnoses. Additional diagnoses reported on the case histories included: ADHD (*n* = 4), dyslexia (*n* = 2), reading disorder (*n* = 1), learning disorder (*n* = 6), anxiety disorder (*n* = 3), and speech and/or language disorder (*n* = 3), and are displayed in Figure 1.

Birth history.

Two of the 10 participants were adopted with unknown birth history; therefore information about birth was only obtained for eight of the 10 participants. Information regarding birth history included NICU stay (*n* = 2; 25%), complications with delivery (*n* = 4; 50%), pre-term delivery (*n* = 3; 37.5%) and/or jaundice (*n* = 2; 25%) are displayed in Figure 2.

Otologic history, handedness and musical instrument.

Otologic history was obtained for all participants (*n* = 10) and included information about previous ear infections (*n* = 6; 60%) and P.E. tubes (*n* = 2; 20%). Nine of the 10 participants (90%) were right-handed and one participant (10%) was left-handed. A majority of the participants had musical training, 70% (*n* = 7) either played a musical instrument or sang in the choir.

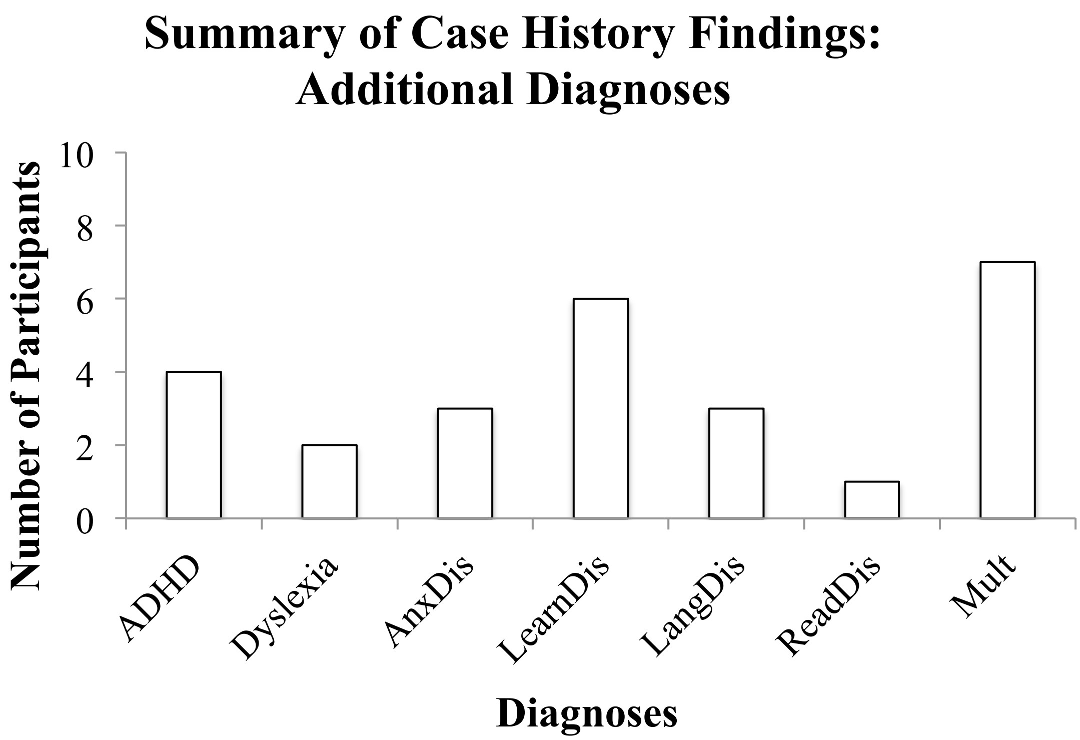

Figure 1. The number of participants with one or more additional diagnoses. Attention-Deficit/Hyperactivity Disorder (ADHD). Anxiety Disorder (AnxDis). Learning Disorder (LearnDis). Language Disorder (LangDis). Reading Disorder (ReadDis). Multiple Diagnoses (Mult).

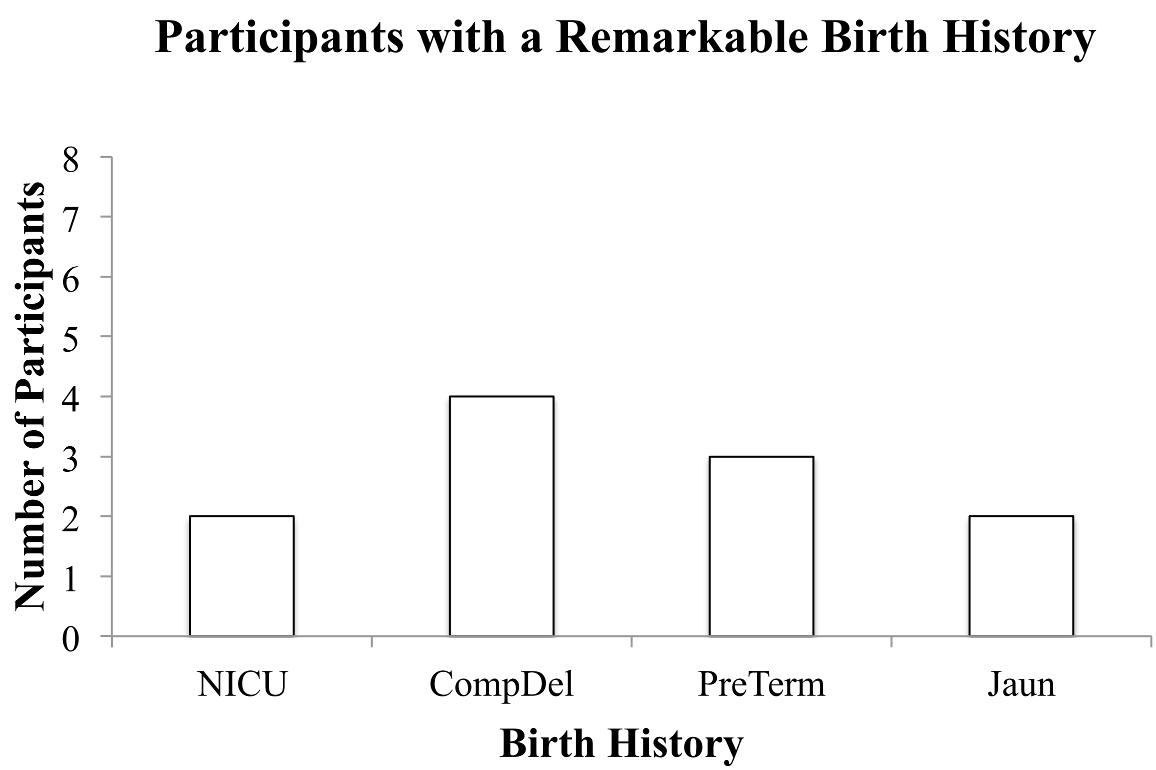

Figure 2. Birth History of all participants. Neonatal intensive care unit (NICU). Complicated delivery (CompDel). Pre-term delivery (PreTerm). Jaundiced (Jaun).

LIFE-UK Teacher Questionnaire Results

Twelve questionnaires that assessed listening behaviors observed in the classroom were completed and returned by the participants' teachers. Questionnaires were returned for seven of the 10 participants (70% response rate). More than one questionnaire (multiple teachers completed questionnaires) was provided for four of six participants (#001, #002 and #011); all other participants had one questionnaire filled in.

Means and standard deviations were calculated for each of the 11 questions on the LIFE-UK. The mean rating for each behavior did not vary across the 11 questions Table 4. Each question received a point value based on the rating and was grouped into categories that described the behavior assessed by each question. No difference in rating of behavior was observed across the four categories or 11 questions (Figure 3).

Table 4

Means and Standard Deviations of LIFE-UK Questions 1-11

	Mean (SD)	Category
Question 1	-0.2 (1.32)	Following Directions
Question 2	0.2 (1.14)	Following Directions
Question 3	-0.4 (1.17)	Attention
Question 4	-0.4 (0.97)	Attention
Question 5	-0.1 (0.99)	Rate of Learning
Question 6	0.2 (1.14)	Involvement in Learning/ Answering Questions
Question 7	-0.22 (0.97)	Involvement in Learning/ Answering Questions
Question 8	0.8 (1.32)	Attention
Question 9	-0.2 (1.40)	Involvement in Learning/ Answering Questions
Question 10	0.2 (1.03)	Involvement in Learning/ Answering Questions
Question 11	-0.4 (1.17)	Following Directions

Note. Behaviors were rated from “very good” (2) to “very poor” (-2). Questions were grouped into overall categories that described the behavior each question assessed: following directions, attention, involvement in class learning and/or answering questions, and rate of learning.

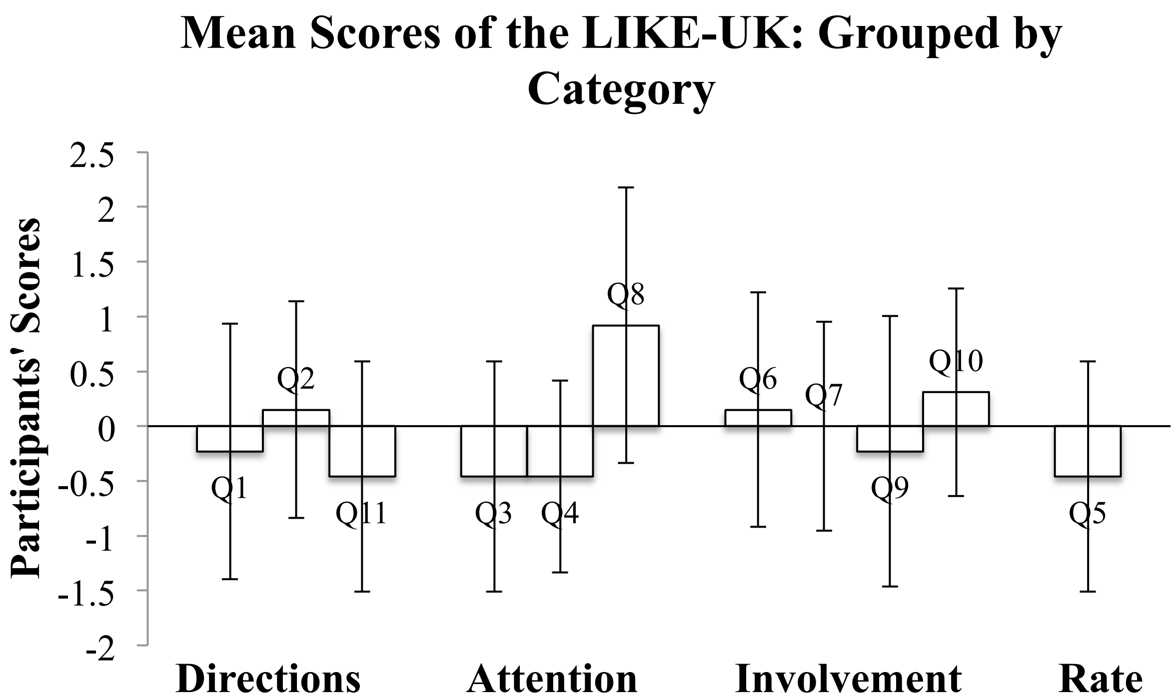

Figure 3. LIFE-UK mean scores with standard deviation bars for questions 1-11. Questions were grouped together based on the behavior that was assessed: Following Directions ("Directions"), Attention, Involvement in Class Learning ("Involvement"), or Rate of Learning ("Rate"). Behaviors were ranked from "very good" (2) to "very poor" (-2).

Hearing Screening

Tympanometry, ARTs, and TEOAEs.

Nine of the 10 participants had Jerger Type A tympanograms bilaterally, and one participant with P.E. tubes had Jerger Type B tympanograms with large ear canal volumes bilaterally. Nine of the 10 participants had measurable ipsilateral and contralateral acoustic reflex thresholds (ARTs) for 500, 1000, and 2000 Hz bilaterally; ARTs could not be obtained on the participant with patent P.E. tubes. Means and standard deviations for ipsilateral and contralateral ARTs that are within normal limits can be found in Table 5.

TEOAEs were present for three or more of the test frequencies in both ears for seven of the 10 participants. Three of the 10 participants had absent TEOAEs at more than three of the test frequencies bilaterally. Means and standard deviations for each test frequency can be seen in Table 6.

Hearing screening.

Nine of the 10 participants passed the puretone hearing screening (15 dB HL from 250-8000 Hz) in both ears. One participant passed for the right ear, but had a mild low frequency hearing loss in the left ear (25 dB HL at 250 Hz and 20 dB HL at 500 and 1000 Hz). This participant saw his physician before proceeding with this study and the physician found the ear to be "safe" (no active middle ear effusion). Word recognition scores ranged from 92 to 96% for the right ear (M = 94.4, SD = 2.07) and 92 to 100% for the left ear (M = 96.8, SD = 3.16).

Table 5

Means and Standard Deviations of Ipsilateral and Contralateral Acoustic Reflex Thresholds

	Right Ear (dB)			Left Ear (dB)		
	500 Hz	1000 Hz	2000 Hz	500 Hz	1000 Hz	2000 H
Ipsilateral ARTs	91.11 (6.01)	89.44 (4.64)	90 (5)	88.33 (5)	85.56 (3.91)	89.44 (7.2
Contralateral ARTs	88.89 (7.82)	90 (5.59)	88.89 (7.82)	90.56 (7.26)	90 (5.59)	88.89 (8.2

Note. Ipsilateral and contralateral acoustic reflex thresholds were measured in dB HL. The standard deviations are listed in parentheses next to the mean values.

Table 6

Means and Standard Deviations of Transient Evoked Otoacoustic Emissions

	1000 Hz	1400 Hz	2000 Hz	2800 Hz	4000 Hz
Right Ear	10.82 (5.86)	12.37 (7.32)	13.33 (7.47)	13.26 (7.77)	7.83 (7.32)
Left Ear	10.94 (5.77)	12.28 (6.42)	12.37 (7.25)	10.48 (5.07)	9.68 (5.21)

Note. Transient evoked otoacoustic emissions (TEOAEs) signal-to-noise ratios (SNRs) were measured in dB HL. The standard deviations are listed in parentheses next to the mean values. TEOAEs were considered to be present at an SNR of 3 dB HL or greater at 1000 Hz or 6 dB HL or greater at 1400 to 4000 Hz.

Screening Test Results

TONI-3, CELF-4 screening test, and CTOPP.

The scaled score results for the TONI-3 for the SusAPD/APD group ranged from 88 to 115 (*M* = 98.80, *SD* = 8.56) and from 98 to 135 (*M* = 114.55, *SD* = 10.91) for the CG. Nine of 10 SusAPD/APD participants scored at or above the respective age criterion score on the CELF-4 Screening Test and one participant scored below the age criterion score. All CG participants scored at or above the respective age criterion score on the CELF-4 Screening Test.

Composite CTOPP scores for the SusAPD/APD group ranged from 85 to 103 for phonological awareness (*M* = 94.30, *SD* = 5.56), 59 to 118 for phonological memory (*M* = 98.60, *SD* = 17.02), and 88 to 133 for rapid naming (*M* = 103.00, *SD* = 13.27). Composite scores for the CG ranged from 94 to 121 for phonological awareness (*M* = 107.35, *SD* = 8.79), 85 to 127 for phonological memory (*M* = 107.70, *SD* = 10.93), and 79 to 136 for rapid naming (*M* = 108.70, *SD* = 12.91).

IVA-CPT.

Scaled scores for sustained auditory attention for the SusAPD/APD group ranged from 38 to 113 (*M* = 85.70, *SD* = 26.88) and scores for sustained visual attention ranged from 68 to 114 (*M* = 94.80, *SD* = 14.81). Five of the participants passed both of the sustained auditory and visual attention portions of the IVA-CPT; two of these participants were previously diagnosed with ADHD and were medicated on test days. Two participants failed the auditory section only and three failed both the auditory and visual sections. Three of the five participants that failed one or both sections of the IVA-CPT had a diagnosis of ADHD (*n* = 2) or had concerns regarding attention already (*n* = 3).

Scores for sustained auditory attention for the CG ranged from 18 to 124 (*M* = 97.20, *SD* = 26.14) and scores for sustained visual attention ranged from 28 to 117 (*M* = 94.75, *SD* = 22.69).

Results revealed that TONI-3 scaled scores were significantly better for the CG (*M* = 114.55, *SD* = 10.91) than SusAPD/APD group (*M* = 98.80, *SD* = 8.56), *t*(28), = -3.98, *p* = .00, *r* = .60. Composite scores for the Phonological Awareness (PA) subtest of the CTOPP were significantly better for the CG (*M* = 107.35, *SD* = 8.79) than for the SusAPD/APD group (*M* = 94.30, *SD* = 5.56), *t*(28), = -4.27, *p* = .00, *r* = .70. Scores on the Phonological Memory and Rapid Naming subtests of the CTOPP, and the Auditory and Visual subsections of the IVA-CPT were not significantly different for the SusAPD/APD group versus the CG, *p* > .05. Levene's test indicated that the variances were significantly different for the PA subtest of the CTOPP, *F*(1, 28) = 4.85, *p* = .04, but were not significantly different for the other screening tests. A summary of the results of each independent t-test that include the means, standard deviations, test statistics, degrees of freedom, and statistical significance for the TONI-3 and PA can be seen in Table 7. Means and standard deviations for screening tests and a trend of better screening test scores for the CG can be found in Figure 4.

Table 7

Independent t-Test Results of Screening Tests for the SusAPD/APD and CG

	Mean (SD)				
	CG (*n* = 20)	SusAPD/APD (*n* = 10)	t	df	Sig. (2-tailed)
TONI-3	114.55 (10.91)	98.80 (8.57)	-3.98	28	.00*
Phonological Awareness	107.35 (8.79)	94.30 (5.56)	-4.95	26.18	.00*
Phonological Memory	107.70 (10.93)	98.60 (17.02)	-1.78	28	.09
Rapid Naming	108.70 (12.91)	103.00 (13.27)	-1.13	28	.27
IVA-CPT Auditory	97.20 (26.14)	85.70 (26.88)	-1.13	28	.27
IVA-CPT Visual	94.75 (22.69)	94.80 (14.81)	.01	28	.99

Note. An alpha value of 0.05 was used to determine significance*. Phonological Awareness, Phonological Memory, and Rapid Naming are the sub-sections of the CTOPP. Standard deviation (SD). Test Statistic (t). Degrees of freedom (df).

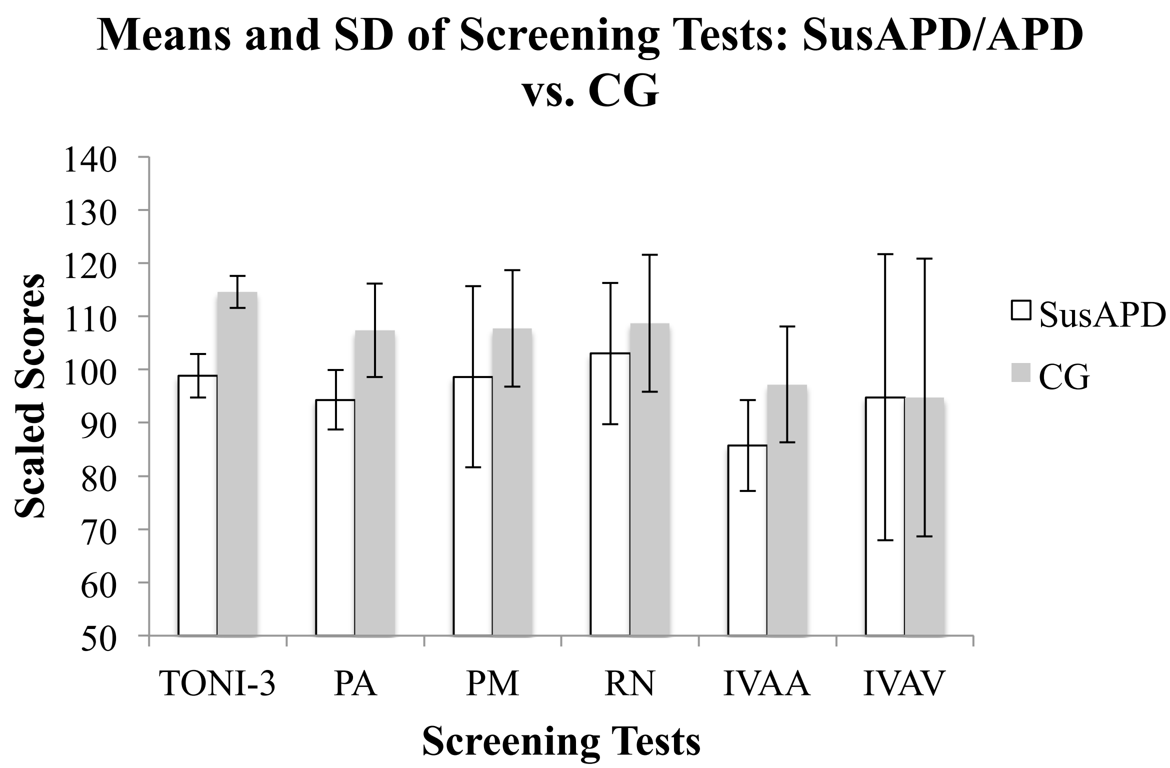

Figure 4. Means and SDs for screening tests of the SusAPD/APD vs. CG. Test of Non-Verbal Intelligence, 3rd Edition (TONI-3). Phonological Awareness (PA). Phonological Memory (PM) Rapid Naming (RN). BrainTrain Integrated Visual and Auditory-Continuous Performance Test- Auditory (IVAA). BrainTrain Integrated Visual and Auditory-Continuous Performance Test- Visual (IVAV).

Auditory Processing Test Battery Results

Raw test scores for the SusAPD/APD group and CG can be found in Appendix H. Means and standard deviations for the SusAPD/APD and CG, and a trend of better AP test scores in the TP domain can be seen in Table 8. Four of the 10 SusAPD/APD participants passed all tests in the APD battery. Two participants failed only one test for one ear (#002 failed the DPT in the left ear; #003 failed the DPT in the right ear). Four of the 10 participants failed two or more AP tests (in one or both ears). The tests that participants failed included: FPT (*n* = 3), DPT (*n* = 4), RGDT (*n* = 2), and AFG +0 dB SNR (*n* = 1). Participants #005 and #010 were unable to provide accurate and consistent responses for RGDT; therefore the test results was reported as inconclusive and excluded from data analysis (for this test only).

Table 8

Means and Standard Deviations of Tests of Auditory Processing for the SusAPD/APD and CG

		Mean (SD)	
Domains	Tests	CG (*n* = 20)	SusAPD/APD (*n* = 10)
Monaural Low Redundancy	CRWR	73.70 (10.98)	70.80 (10.51)
	CRWL	71.90 (10.31)	72.40 (13.39)
	AFG +8 dB SNR	9.75 (1.94)	9.30 (1.95)
	AFG 0 dB SNR	9.95 (2.21)	9.00 (1.70)
Dichotic Listening	DDTR	96.00 (3.92)	96.50 (3.37)
	DDTL	93.75 (8.68)	90.75 (9.51)
Temporal Processing	FPTR	90.33 (13.24)	78.67 (20.32)
	FPTL	87.67 (11.70)	72.00 (29.78)
	DPTR	78.00 (17.85)	52.00 (23.48)
	DPTL	77.33 (15.36)	50.67 (24.18)
	RGDT	5.48 (3.50)	6.24 (3.82)
Sound Localization and Lateralization	LiSN-S		
	LC-SRT	-1.08 (1.09)	-0.66 (0.97)
	HC-SRT	-12.53 (1.56)	-11.74 (1.91)
	Talker Adv.	5.79 (1.85)	4.85 (1.48)
	Spatial Adv.	9.88 (2.43)	9.55 (2.30)
	Total Adv.	11.43 (2.13)	11.07 (2.10)

Note. Time Compressed and Reverberated Words, right and left ears (CRWR and CRWL). Auditory Figure Ground (AFG). Signal to Noise Ratio (SNR). Dichotic Digits Test, right and left ears (DDTR and DDTL). Frequency Pattern Test, right and left ears (FPTR and FPTL). Duration Pattern Test, right and left ears (DPTR and DPTL). Random Gap Detection Test (RGDT). Listening in Spatialized Noise- Sentences Test (LiSN-S): Low-Cue Speech Recognition Threshold (LC-SRT), High-Cue Speech Recognition Threshold (HC-SRT), Talker Advantage (Talker Adv.), Spatial Advantage (Spatial Adv.), and Total Advantage (Total Adv.).

Monaural low redundancy (MLR).

Time compressed and reverberated words (CRW).

Percentage scores for the SusAPD/APD group on the CRW ranged from 56 to 84% (*M* = 70.80, *SD* = 10.51) and 52 to 96% (*M* = 72.40, *SD* = 13.39) for the right and left ears respectively. Percentage scores for the CG on the CRW ranged from 56 to 96% (*M* = 73.70, *SD* = 10.98) and 56 to 92% (*M* = 71.90, *SD* = 10.31) for the right and left ears respectively.

Auditory figure ground (AFG).

Scaled scores for the SusAPD/APD group on the AFG +8 dB SNR and 0 dB SNR ranged from 7 to 12 (*M* = 9.30, *SD* = 1.95) and 6 to 12 (*M* = 9.00, *SD* = 1.70) respectively. Scaled scores for the CG on the AFG +8 dB SNR and 0 dB SNR ranged from 6 to 12 (*M* = 9.75, *SD* = 1.94) and 6 to 16 (*M* = 9.95, *SD* = 2.21) respectively.

Dichotic listening (DL).

Dichotic double digits test (DDT).

Percentage scores for the SusAPD/APD group on the DDT ranged from 90 to 100% (*M* = 96.50, *SD* = 3.37) and 67.5 to 100% (*M* = 90.75, *SD* = 9.51) for the right and left ears respectively. Percentage scores for the CG on the DDT ranged from 85 to 100% (*M* = 96.00, *SD* = 3.92) and 62.5 to 100% (*M* = 93.75, *SD* = 8.68) for the right and left ears respectively.

Temporal processing (TP).

Frequency pattern test (FPT).

Percentage scores for the SusAPD/APD group on the FPT ranged from 46.67 to 100% (*M* = 78.67, *SD* = 20.32) and 20.00 to 93.33% (*M* = 72.00, *SD* = 29.78) for the right and left ears respectively. Percentage scores for the CG on the FPT ranged from 46.67 to 100% (*M* = 90.33, *SD* = 13.24) and 46.67 to 100% (*M* = 87.67, *SD* = 11.70) for the right and left ears respectively.

Duration pattern test (DPT).

Percentage scores for the SusAPD/APD group on the DPT ranged from 13.33 to 80% (*M* = 52.00, *SD* = 23.48) and 13.33 to 86.67% (*M* = 50.67, *SD* = 24.18) for the right and left ears respectively. Percentage scores for the CG on the DPT ranged from 46.67 to 100% (*M* = 78.00, *SD* = 17.85) and 40.00 to 100% (*M* = 77.33, *SD* = 15.36) for the right and left ears respectively.

Random gap detection test (RGDT).

Composite gap thresholds for the SusAPD/APD group on the RGDT ranged from 2.75 to 11.67 milliseconds (*M* = 6.24, *SD* = 3.82). Two of the 10 participants were unable to complete the RGDT. Composite gap thresholds for the CG on the RGDT ranged from 2.00 to 16.67 milliseconds (*M* = 5.48, *SD* = 3.50).

Sound localization and lateralization.

Listening in spatialized noise- sentences test (LiSN-S).

Scores for the SusAPD/APD group on the LiSN-S ranged from -1.9 to 0.9 (*M* = -0.66, *SD* = 0.97) for low-cue SRT, -14.4 to -7.7 (*M* = -11.74, *SD* = 1.91) for high-cue SRT, 2.6 to 6.7 (*M* = 4.85, *SD* = 1.48) for talker advantage, 6.5 to 13.6 (*M* = 9.55, *SD* = 2.30) for spatial advantage, and 8.6 to 15.1 (*M* = 11.07, *SD* = 2.10) for total advantage. Scores for the CG on the LiSN-S ranged from -3.2 to 0.8 (*M* = -1.09, *SD* = 1.09) for low-cue SRT, -14.8 to -7.7 (*M* = -12.53, *SD* = 1.56) for high-cue SRT, 1.8 to 8.4 (*M* = 5.79, *SD* = 1.85) for talker advantage, 7.2 to 15.1 (*M* = 9.88, *SD* = 2.43) for spatial advantage, and 6.6 to 15.2 (*M* = 11.43, *SD* = 2.13) for total advantage. Figure 5 shows similar results for the SusAPD/APD group and CG for each condition of the LiSN-S test.

Results revealed that DPT RE condition test scores were significantly better for the CG (*M* = 78.00, *SD* = 17.85) than for the SusAPD/APD group (*M* = 52.00, *SD* = 23.48), *t*(28), = -3.39, *p* = .00, *r* = .54. Results also revealed that DPT LE condition test scores were significantly better for the CG (*M* = 77.33, *SD* = 15.36) than for the SusAPD/APD group (*M* = 50.67, *SD* = 24.18), *t*(28), = -3.69, *p* = .00, *r* = .57. The remaining tests did not show a significant difference in scores between the SusAPD/APD and CG, *p* > .05. Levene's test indicated that the variances were significantly different for the FPT LE condition, *F*(1, 28) = 21.02, *p* = .00, but were not significantly different for the other AP tests. Independent t-test results of the AP tests for the SusAPD/APD and CG, and significant differences for DPT RE and DPT LE conditions can be found in Table 9.

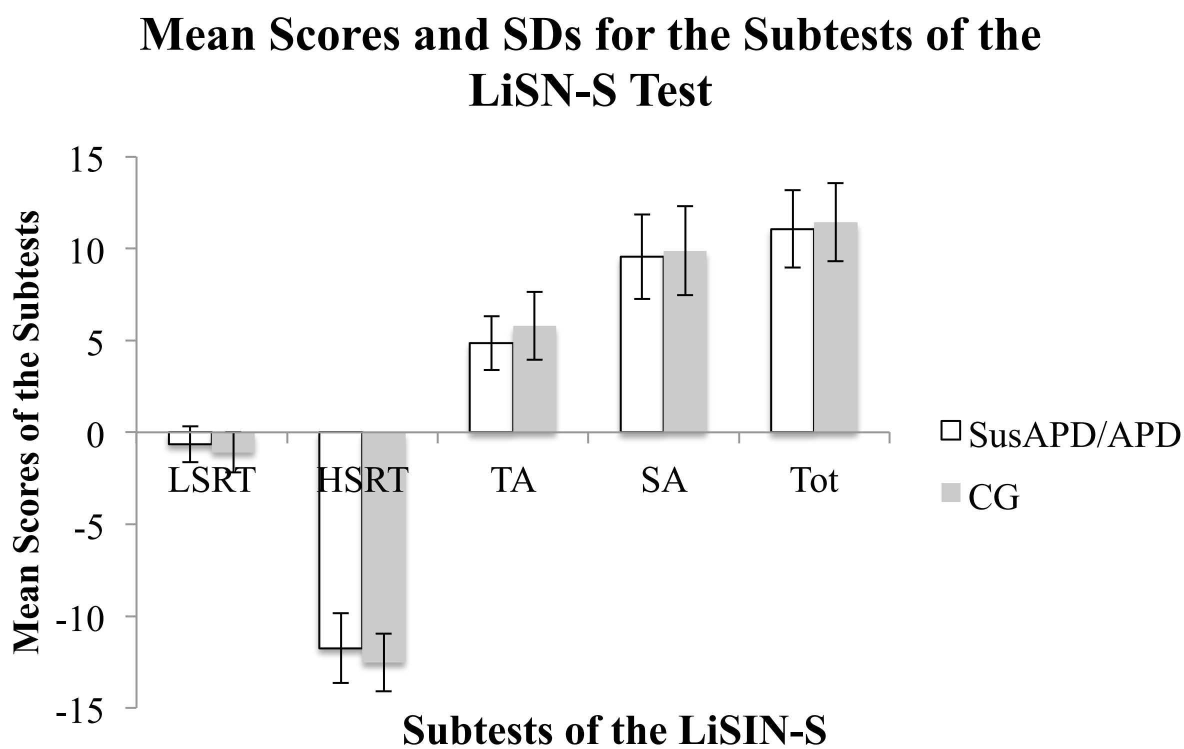

Figure 5. Mean test scores and standard deviations for the subtests of the LiSN-S Test. Listening in Spatialized Noise- Sentences Test (LiSN-S): Low-Cue Speech Recognition Threshold (LSRT), High-Cue Speech Recognition Threshold (HSRT), Talker Advantage (TA), Spatial Advantage (SA), and Total Advantage (Tot).

Table 9

Independent t-Test Results of the Tests of Auditory Processing for the SusAPD/APD and CG

Domains	Tests	t	df	Sig. (2-tailed)
Monaural Low Redundancy	CRWR	-.69	28	.50
	CRWL	.11	28	.91
	AFG +8 dB SNR	-.60	28	.56
	AFG 0 dB SNR	-1.19	28	.24
Dichotic Listening	DDTR	.34	28	.73
	DDTL	-.87	28	.39
Temporal Processing	FPTR	-1.90	28	.07
	FPTL	-1.60	10.41	.14
	DPTR	-3.39	28	.00*
	DPTL	-3.69	28	.00*
	RGDT	.51	26	.62
Sound Localization and Lateralization	LiSN-S			
	LC-SRT	1.04	28	.31
	HC-SRT	1.21	28	.24
	Talker Adv.	-1.39	28	.17
	Spatial Adv.	-.35	28	.73
	Total Adv.	-.44	28	.67

Note. All differences were reported as significant at $p < .05$*. Time Compressed and Reverberated Words, right and left ears (CRWR and CRWL). Auditory Figure Ground (AFG). Signal to Noise Ratio (SNR). Dichotic Digits Test, right and left ears (DDTR and DDTL). Frequency Pattern Test, right and left ears (FPTR and FPTL). Duration Pattern Test, right and left ears (DPTR and DPTL). Random Gap Detection Test (RGDT). Listening in Spatialized Noise- Sentences Test (LiSN-S): Low-Cue Speech Recognition Threshold (LC-SRT), High-Cue Speech Recognition Threshold (HC-SRT), Talker Advantage (Talker Adv.), Spatial Advantage (Spatial Adv.), and Total Advantage (Total Adv.).

Chapter 5

Discussion

Children with APD are a heterogeneous group that can present with a spectrum of symptoms for the same disorder, making the assessment and rehabilitation of this population complex. Children with suspected APD are likely to have additional disorders (Witton, 2010). Therefore audiologists must be careful when selecting a test battery for their patients because language, cognition and/or attention may negatively impact the assessment and lead to a misdiagnosis. While APD can occur as the sole disorder, it is often accompanied by other disorders (Witton, 2010). If the APD diagnostic criteria are met, and the presence of other disorders has been ruled out or accounted for, then an audiologist should diagnose APD. The involvement of an interdisciplinary team is ideal because it will assist with differential diagnosis and development of recommendations for rehabilitation that address the multiple concerns (Dawes & Bishop, 2009; Musiek et al., 2005; Witton, 2010). Audiologists need to be able to identify possible co-occurring disorders to assist with the appropriate administration of APD tests and/or referrals.

Additional Disorders in Children with Suspected or Confirmed APD

Of the 10 participants in the SusAPD/APD group, nine presented with co-occurring disorder(s). LD was the most common amongst the small sample, followed closely by ADHD, LI, anxiety disorder, dyslexia and RD. Of the nine participants, seven had two or more diagnoses. A good case history (oral or written) could give the audiologist information about co-occurring disorders. However, severity of the disorder may be unknown to the audiologist because parents may have forgotten copies of the previous assessments or the assessments are outdated (over a year old). It is important that audiologists assess for APD and not let known or unknown additional disorders interfere with the accurate assessment of the CANS. Therefore the use of screening tests is recommended before all tests of auditory processing are administered.

Case highlight: Comparison of #006 and #007.

A case comparison was conducted between two participants (#006 and #007) with a similar profile (e.g., age, gender, case history, and co-occurring disorders) (Table 10). Participant #006 was included in this study and participant #007 was excluded from this study. Participant #006's co-occurring disorders did not present as severely as participant #007's disorders as identified by the screening tests. If screening tests were not used in this study, the participants would have appeared, on paper at least, similarly. This would have potentially led to a false positive result for participant #007 and recommendations based on case history and APD test results only (therefore leaving out educational psychology referral and ADHD evaluation for participant #007).

While this study had a small sample size, the screening test results highlighted the importance of using screening tests for both information purposes (e.g., to assist with treatment recommendations or next steps) and for exclusion criteria (e.g., to identify children who cannot accurately be assessed for APD). This study found that the CG performed significantly better on the TONI-3 and PA subtest of the CTOPP than the SusAPD/APD group. And, although non-significant, scores of the remaining screening tests were higher (better) for the CG than the SusAPD/APD group. These results support the need and benefit to using screening tests prior to administering an APD evaluation when diagnostic tests have not been completed in the areas of language, phonological processing, intelligence, and/or attention.

Case highlight: Participant #007.

Eleven children were initially included in the participant pool. One participant (#007), male, 11 years, 11 months, was excluded from data analysis. According to the case history, the child was diagnosed with dyslexia, reading disorder (reading was most recently measured at a first grade level), mixed expressive-receptive language delay, and learning disability. He was suspected of having APD. Due to a score outside of normal limits (< 80) on the TONI-3 this child was not assessed for APD. In addition to meeting this exclusion criterion, the participant's scores were also outside of normal limits on the CELF-4 Screening Test, the PA subtest of the CTOPP, and on both the auditory and visual portions of the IVA-CPT. No further testing for this study was completed. While even this child's case history indicated he might not be a good candidate for an APD assessment (due to the complexity of his multiple diagnoses), the screening tests picked up on a disorder that may be contributing to his difficulties. The participant failed both subtests of the Brain Train IVA-CPT attention task. Screening tests not only confirmed this child was not appropriate for the APD assessment but they also helped make appropriate referrals. If a good case history was not obtained and/or screening tests performed then this participant could have been misdiagnosed with APD despite the multiple confounding factors.

Table 10

Case Comparison: Participants #006 and #007

		Participant (Age)	
		#006 (11, 6)	#007 (11, 11)
Case History	Birth History	Unremarkable	Unremarkable
	Developmental History	Normal	Normal
	Medical History	Unremarkable	Unremarkable
	Other Diagnoses	Dyslexia, RD, ADHD, LD- Dysgraphia, Anxiety Disorder	Dyslexia, RD, LD, LI
	Otological History	Unremarkable	Unremarkable
Hearing Screening		WNL	RE- WNL LE- 45 dB HL at 4000 Hz
Screening Tests	TONI-3 (Criterion)	115 (≥80)	78 (≥80)
	CELF-4 Screening Test (Criterion)	31 (≥19)	12 (≥19)
CTOPP	PA (Criterion)	103 (≥80)	73 (≥80)
	PM (Criterion)	118 (≥80)	85 (≥80)
	RN (Criterion)	94 (≥80)	88 (≥80)
BrainTrain	IVA-CPT Auditory (Criterion)	76 (≥85)	<50 (≥85)
	IVA-CPT Visual (Criterion)	82 (≥85)	<50 (≥85)

Note. Reading disorder (RD). Attention-Deficit/Hyperactivity Disorder (ADHD). Learning disability (LD). Language impairment (LI). Within normal limits (WNL). Test of nonverbal Intelligence, 3rd Ed. (TONI-3). Clinical Evaluation of Language Fundamentals, 4th Ed. Screening Test (CELF-4). Comprehensive Test of Phonological Processing (CTOPP). Phonological Awareness (PA), Phonological Memory (PM), and Rapid Naming (RN) are subtests of the CTOPP. Integrated Visual and Auditory Continuous Performance Test (IVA-CPT).

LI, RD, ADHD and cognition.

Participant #007's complex screening test results are not surprising considering several studies support that additional disorders can not only co-occur with APD, but may also share symptoms and, for some, a behavioral profile with it (Chermak et al., 1998; Ferguson et al., 2011; Sharma et al., 2009). Sharma et al. (2009) found their criteria for APD, LI, and RD identified almost half (47%) of their school-aged participants with all three of the disorders, and that 32% were identified with a combination of two of the three disorders. In addition to disorders co-occurring with APD, some disorders share symptoms with APD that make it difficult to distinguish one from another (Dawes & Bishop, 2009; Ferguson et al., 2011; Moore et al., 2010; Musiek et al., 2005).

Ferguson et al. (2011) found that a group of school-aged children diagnosed with SLI and a group diagnosed with APD performed similarly on AP questionnaires and behavioral test measures (both groups were outperformed by the CG). The study also found that the APD and SLI group presented with similar behavior profiles and parent reports, indicating that disorders with similar symptoms and profiles may lead to a diagnosis that reflects the referral route of the child (i.e. SLI from an SLP or APD from an audiologist). Again, highlighting the likelihood of the presence of additional co-occurring disorders in a child with suspected APD.

Moore et al. (2010) found AP test scores significantly correlated to scores on cognitive measures. The children who had difficulty on the AP tests also showed poor performance on the cognitive measures (Moore et al., 2010). Similarly, this study showed that the SusAPD/APD group performed significantly poorer on cognitive measures (i.e., TONI-3) than the CG, highlighting the need to use additional measure(s) with children suspected of APD to determine if accurate assessment of APD is possible.

Chermak et al. (1999) stresses the importance of a differential diagnosis of APD due to similarly presenting behaviors as ADHD. Although they share a similar behavior profile, APD and ADHD are two separate disorders that were found to have characteristic behaviors that clearly separated the two disorders apart from one another (Chermak et al., 1998). The Brain Train IVA-CPT evaluated sustained auditory and visual attention. If a participant scored outside of normal limits on this task, the participant was not excluded from the AP evaluation but the session was modified to fit the attention needs of the participants (i.e. frequent breaks and/or multiple test days) (ASHA, 2005). According to Chermak et al. (1999), APD can be assessed in persons with ADHD if s/he takes his/her medication as prescribed, testing time is shortened and includes breaks, and also if there are snacks/toys provided by a parent/guardian to motivate the participant to complete the test at accurately and efficiently as possible as seen in this study, specifically with participant #004.

Case highlight: Participant #004.

According to the case history, participant #004 (male, 10 years, 8 months) was diagnosed with ADHD prior to coming in for the research study. His parents reported that he was not on any medication for ADHD due to his heart murmur. They are currently doing nothing for his ADHD. He was suspected of having APD. The participant failed both of the sustained auditory and visual attention portions of the BrainTrain IVA-CPT, which supported his diagnosis of ADHD. AP testing was modified to account for ADHD by giving the participant frequent breaks (between tests), re-directing, and dividing up his test sessions into multiple test sessions. This participant passed all of the tests in the APD battery. If attention was not controlled for, this participant may have had difficulty attending to and appropriately responding to the tasks, which may have led to an inaccurate diagnosis of APD.

In this case example the disorder was known and the treatment (or lack thereof, in this case) was also known. Often this is not the case or the severity is unknown. When there is a suspicion of additional disorders, screening tests can be used to determine whether to continue with the AP evaluation or if a referral to another professional before he/she is assessed for APD to rule out (or identify) the suspected disorder is more appropriate.

LIFE-UK

The LIFE-UK questionnaire was given to the participants' teachers prior to the evaluation to answer questions related to their observation of the child's classroom behaviors. Seven of the 10 participants returned the questionnaires which is a high response rate for surveys (Evangelista, Poon, & Albaum, 2012; Kereakoglow, Gelman, & Patridge, 2013). Evangelista et al. (2012) found response rates for personal interview surveys varying from 35 to 64% and stated that motivation for responding to surveys is the expected outcome or reward, which in this case is a diagnosis (or not) of APD. Kereakoglow et al. (2013) found that the response rate for mailed surveys that were enhanced with color and graphics (in attempt to increase response rate) was still low and did not differ from the response rate of a standard black and white survey: 33.7% and 36.9%, respectively. What potentially affected the data is the fact that four of the seven participants returned multiple LIFE-UK forms because more than one teacher provided feedback.

The researchers chose to group questions into categories that they felt best described specific learning behaviors. The categories included: following directions, attention, involvement of learning and answering questions, and rate of learning. A pattern could not be observed from the categories but future directions should include a large sample size and consider correlation analyses with the pre-screener results. Again, the fact that more than half of the participants with returned questionnaires had multiple questionnaires representing their behaviors could have skewed the data.

Hearing Screening

An audiologic evaluation or, at a minimum, a hearing screening with strict criteria, should be performed prior to all APD assessments. This will help the audiologist rule out hearing loss and/or other auditory disorders as cause for the perceived listening difficulties. Both AAA (2010) and ASHA (2005) stated that patients with mild, symmetrical, hearing loss can be assessed for APD if appropriate tests are chosen and modifications are made as needed (e.g., intensity increased). Results should be interpreted using guidelines for conducting APD testing with people with hearing loss. People with severe hearing loss or significantly degraded word recognition ability cannot be assessed accurately using tests of auditory processing (AAA, 2010; Baran, 2007).

Chronic Eustachian tube dysfunction and/or patent P.E. tubes.

According to Paradise et al. (2005), otitis media with effusion (OME) is the second most common illness after the common cold. Children who suffer from persistent OME typically have at least a mild conductive hearing loss. Lack of auditory stimulation caused by OME was previously thought to have detrimental effects on cognition, speech, and development, including auditory processing; therefore, a study was done to evaluate this hypothesis (Paradise et al., 2005). After multiple rounds of antibiotics, or chronic ME effusion, P.E. tubes are often used to treat OME. Paradise et al. (2005) found no difference in performance between children treated immediately with P.E. tubes and children with delayed treatment of P.E. tubes (up to nine months after onset of OME) on tests of intelligence, speech and auditory processing. However, Moore (2007) found that children with APD often have a complex history of ear infections and, in some cases, P.E. tubes. According to the case history, six out of the 10 participants in this study had a history of OME and two participants were treated with one or more sets of P.E. tubes.

It is not uncommon for children with suspected APD to have a long history of ear infections and/or P.E. tubes (Moore, 2007). Tympanometry will be important to indicate if the middle ear space is functioning normally or if there is negative pressure and/or fluid in the middle ear space. If the middle ear appears healthy, the audiologist can proceed with the evaluation, however, if middle ear pathology is suspected, then a referral to an Ear, Nose and Throat (ENT) doctor should be made. Tympanometry will also confirm if the P.E. tubes are patent, which is necessary before proceeding with additional tests. If the hearing screening or immittance results indicate something abnormal (outside normal limits) such as patent P.E. tubes and a low frequency hearing loss, then a physician needs to see the child to obtain clearance to proceed with the APD testing (or to wait until the ear is “safe”). Once the physician has cleared the ear as “safe” (no middle ear effusion) then AAA (2010) states that if the hearing loss is mild and word recognition ability is good, APD can still be assessed.

One participant in this study, #003, had a history of OME with present P.E. tubes. Although tympanometry indicated that the tubes were patent, he had a mild low frequency (LF) hearing loss in the left ear (25 dB HL at 250 Hz and 20 dB HL at 500 and 1000 Hz). Before continuing with the APD evaluation, he was referred to his ENT to ensure that his ear was "safe" before proceeding with testing. The ENT cleared him for testing because there was no ME effusion. Since the hearing loss was mild in nature and he had good word recognition ability in the ear with the mild LF hearing loss (92%), the AP stimuli were presented without adjustments and in compliance with the recommendations of AAA (2010). Participant #003 passed all tests of AP.

Reduced and/or absent TEOAEs.

TEOAEs are present in most of the normal hearing (≤ 20 dB HL) population (Glattke & Robinette, 2007; Nozza, Sabo, & Mandel, 1997; Taylor & Brooks, 2000). Three of the 10 participants had reduced or absent TEOAEs at three or more test frequencies in both ears. According to Taylor and Brooks (2000), TEOAE amplitude can be adversely affected by OME, negative middle ear pressure, and a history of OME that caused scarring on the tympanogram. Each of the three participants with reduced and/or absent TEOAEs had a reported history of OME with or without P.E. tubes. These participants were included in data analysis because additional testing for hearing sensitivity was obtained; the pure tone air-conduction screening at 15 dB HL confirmed that hearing was within normal limits, in conjunction with normal tympanograms, ARTs and WRS.

Auditory Processing Test Battery

This study included tests from four domains of auditory processing: MLR, DL, TP, and localization and lateralization. Results showed differences in test performance across the four domains of auditory processing. When reviewing the test results related to pass vs. fail (in at least one ear) by category, one participant failed MLR, one participant failed DL, and one participant failed one subtest of the localization and lateralization test. Temporal processing testing resulted in 15 failures across the three tests in the domain (FPT, DPT, and RGDT). DPT scores were significantly poorer for the SusAPD/APD group compared with the CG. All other temporal tests had a lower mean score for the SusAPD/APD group, but the results were not significant.

Tests of temporal processing have been reported to have high sensitivity and specificity in identifying APD (Musiek, 1994; Musiek et al., 2011). Musiek et al. (2011) compared sensitivity, specificity and efficacy across tests of MLR, DL, and TP domains and found FPT had the best sensitivity, specificity and efficacy, followed by DDT, competing sentences, and filtered speech. In a study by Sharma et al. (2009) that included 68 children with suspected APD, FPT was the test that the majority of their participants failed, followed by DDT, RGDT, and masking level difference. These studies highlight the necessity of including TP tests in an APD test battery because of their ability to most accurately "catch" APD.

Tests of DL have high sensitivity and specificity for dysfunction in the corpus callosum, and should also be included in the test battery (Musiek, 1983; Musiek et al., 2011; Sharma et al., 2009). A classic finding in DL tests of persons with APD is a right ear advantage (scores for the right ear are considerably better than left ear scores) in patients less than 12 year of age that should disappear with maturation (AAA, 2010; Noffsinger et al., 1994). When a poorer left ear score persists past 12 years of age, APD is likely (AAA, 2010). Unfortunately, due to the small sample size, age bands of participants could not be examined , which potentially masked the observation of any right ear advantages amongst the participants. Although MLR tests appear to have the lowest sensitivity and specificity in identifying APD, Musiek et al. (2011) recommends including a test of this domain in the APD test battery to offer a more complete picture of the patient's difficulties, especially auditory closure. Only one participant in this study had difficulty in the MLR domain, specifically on the AFG 0 dB SNR condition. If the battery used in this study was heavily loaded with tests from the MLR domain, the sensitivity and specificity of the overall APD test battery would decrease, and potentially result in a misrepresentation of the difficulties (or lack thereof) experienced by the SusAPD/APD group (Musiek et al., 2011).

Cameron et al. (2009) found that the newly developed LiSN-S test for the North American population showed good test-retest reliability. Sensitivity and specificity measures have not been reported yet, but the test is used as a fairly easy test to administer for identifying the ability to use sound localization cues for binaural processing. Although this study did not look at test-retest reliability, the researchers did find that this test was easy to administer.

Inconclusive test results.

Two of the 10 SusAPD/APD participants had difficulty completing the RGDT. In the clinical setting the audiologist should administer another test of temporal processing that assesses the same skill, temporal resolution, but uses a different test (e.g., Gaps-in-

Noise (GIN) test) would be an appropriate substitute for RGDT (Shinn, Chermak, & Musiek, 2009). Such instances require the audiologist to be familiar with available and clinically appropriate tests of AP.

Length of the APD test battery and motivation.

This study also highlighted that length of test sessions and motivation are important factors to consider when scheduling an APD evaluation. Testing was broken up into two sessions, lasting 1.5 hours each session. Some participants completed testing in one day with a 2-hour break in between sessions, while other participants returned up to one week after the first assessment to complete testing. Tests were re-administered to six of the 10 participants (with and without ADHD) when attention, fatigue and/or lack of motivation were observed. Some participants were able to provide accurate results when re-directed back to the task, but others came back another day to complete testing. Parents motivated their children with snacks, computer games, and/or a prize at the end for completing the evaluation. Many of the children responded positively to this technique, and test results improved much like the findings in Silman et al. (2000). Therefore using motivational techniques for all children should be considered.

AAA (2010) suggested that the assessment for APD should be a maximum of 45- to 60-minutes long. Long test sessions lower the efficacy of the entire test battery when lack of attention, motivation, and fatigue become a factor during the evaluation (AAA, 2010; ASHA, 2005).

Limitations and Future Directions

The sample size of this study was small therefore the power in the analysis was low. For this reason, correlations between the results of the LIFE-UK, results of the screening tests, case history, and results of the APD test battery were not performed. The small sample size also limited the researchers' ability to separate the participants into age bands and into groups of suspected APD vs. identified APD vs. CG, for the purposes of analysis. In the future, a larger sample size (e.g., n=30) of the SusAPD/APD group needs to be recruited and tested. A larger sample size will strengthen the power in the statistical analyses and therefore assist in more conclusive findings.

Normative data for the LIFE-UK would be beneficial to assist in analyzing the differences between the CG and SusAPD/APD group. This normative data would assist in making the LIFE-UK results for individual participants easier to score and make recommendations (e.g., APD testing, other professionals, etc.). Differences in the results between the SusAPD/APD and CG could provide the clinician with a quick reference of how the child compares to his/her typically-developing peers and if an APD evaluation is warranted.

Conclusion

Even with a small sample size, this study was still able to highlight the importance of incorporating screening tests into the APD evaluation and the sensitivity of temporal processing tests in identifying APD. Clinicians can expect that the person coming to them for an APD evaluation may already have a diagnosis or show symptoms of a co-occurring disorder. When supplemental reports regarding additional diagnoses are unavailable or out of date and an interdisciplinary team is not feasible, screening tests will give the clinician a better picture of the child and will assist with identifying how best to proceed. The APD test battery should include tests of temporal processing along with other test categories (Jerger & Musiek, 2000). Although APD can be difficult to accurately diagnose due to its heterogeneous nature, use of screening tests and a core APD test battery will assist in making accurate diagnoses, appropriate recommendations for rehabilitation, and/or to assist with appropriate referrals to other professionals.

APPENDIX A

Descriptions of Additional Questionnaires

Children's Auditory Processing Performance Scale (C.H.A.P.P.S.).

The C.H.A.P.P.S. is a 25-item scaled questionnaire for teachers and/or caregivers to rate a child's listening difficulties in various conditions (i.e. noise, quiet, ideal, with multiple inputs, conditions requiring memory sequencing, and conditions requiring sustained auditory attention) in comparison to his/her peers (Smoksi et al., 1992; Smoski et al., 1998). A scale of +1 to -5 is used to rate the degree of listening difficulty the child is having: +1= less difficulty, 0= same amount of difficulty, -1= slightly more difficult, -2= more difficulty, -3= considerably more difficulty, -4= significantly more difficulty, -5= cannot function at all. The C.H.A.P.P.S. is used to refer children for an APD evaluation and to assist in intervention and management if a diagnosis is given after a full evaluation (Smoski et al., 1992; Smoski et al., 1998).

Fisher's Auditory Problems Checklist.

The Fisher's Auditory Problems Checklist is a 25-item checklist that is normed on children for individual grade levels: kindergarten to sixth grade (Fisher, 1976). It is completed by teachers or caregivers in regard to the child's academic performance, and includes questions about behaviors/symptoms that are commonly associated with APD (Fisher, 1976).

Screening Instrument for Targeting Education Risk (S.I.F.T.E.R.).

The S.I.F.T.E.R. consists of five categories with three questions each (15 total): academics, attention, communication, class participation, and school behavior (Anderson, 1989). Teachers administer it to school-aged children with listening difficulties. It can be used to compare a child to his/her peers, or to track self progress prior to and after intervention (i.e. FM system use). The teacher ranks the student based on his/her performance in the classroom and can include comments to further explain areas of difficulty (Anderson, 1989). The S.I.F.T.E.R. is best used for children in first to fifth grade (Anderson, 1989).

Listening Inventory for Education, United Kingdom (L.I.F.E.-UK).

The L.I.F.E.- UK is a 13-item scaled screening tool for teachers to complete based on the original L.I.F.E. created by Karen Anderson and Joseph Smaldino. Teachers rate the child's difficulties and behavior that are observed in the classroom (Canning, 1999). The rating scale ranges from very good to very poor and includes extra space for additional comments.

There are 11 questions that address observed listening behaviors in the classroom and two questions that are only applicable if a classroom or personal amplification system is used. Each question addresses a different listening behavior: (1) Following class directions (2) following individual directions (3) overall attention span (4) on task behavior (5) rate of learning (speed of following instruction) (6) involvement in class discussions (volunteers more, makes appropriate contributions) (7) contributes when working in a group (8) paying attention to multimedia (e.g. video, OHP) (9) willingness to answer questions (10) answering questions in an appropriate and relevant manner (11) amount of repair behavior (this refers to asking questions, to teacher or peer, in order to clarify what is required) (12) overall noise levels in the class while working in groups (13) noise levels in the class during while class teaching.

This tool can be used to suggest management strategies (i.e. FM system) if any difficulties are identified and to assess the benefit of those management strategies that were put into place (Canning, 1999). A personal frequency modulated (FM) system is a device that consists of two receiver earpieces worn by the child and a microphone worn by the teacher (Nelson, Poole, & Munoz, 2013). The FM system delivers the teacher's voice directly into the child's ears, overcoming background noise that may interfere with processing auditory signals (Nelson et al., 2013).

Children's Home Inventory of Listening Difficulties (C.H.I.L.D.).

The C.H.I.L.D. is a 15-item screening tool exclusively for parents or caregivers to describe the child's listening behaviors at home (Anderson & Smaldino, 2000). The parents give a rating of one through eight (1=huh- the child is not aware that someone is talking; 8= great- the child hears every word) for each question. The C.H.I.L.D. also includes a section for the child to rate those same 15-items based on his/her perception of his/her own listening skills. The screening tool may be used with children 3-12 years of age (Anderson & Smaldino, 2000).

APPENDIX B

Participants needed for Auditory Processing Research

Has your child been diagnosed with Auditory Processing Disorder (APD) or is he/she suspected of having listen-ing problems?

If so, please consider participating in this research project!

Why?

To evaluate the new normative data collected for several routinely used auditory processing tests. The data collected in this study will provide an important comparison to the current normative data used with testing for auditory processing disorder (APD). It will also assist with future clinical assessment and research studies in this area.

What is auditory processing?

It is a term used to describe the way the auditory pathways in the brain process what is heard, or how we listen.

Where?

All testing will be conducted in Dr. Smart's Hearing And Listening Laboratory (HALL) at Towson University in Van Bokkelen Hall.

When?

Appointments will be offered throughout the year during the school day, after-school hours, weekends, and during holiday breaks. Total test time is estimated at around 4 hours over 2 sessions.

Who?

We are looking for children (males and females) ages 7,0—12,11 who have been diagnosed with APD or are suspected of having APD.

Interested in learning more?

If your child fits the profile above and is willing to volunteer in our study, please contact Dr. Jennifer Smart (Associate Professor) at 410-704–3105 or JSmart@towson.edu for more

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY (PHONE: 410-704-2236).

APPENDIX C

TOWSON UNIVERSITY

Department of Audiology, Speech-Language Pathology, and Deaf Studies

INFORMED CONSENT FORM

Project title: Testing for Auditory Processing Disorder in Children Using New Normative Values

Principal Investigators:
Jennifer L. Smart, Ph.D. and Diana C. Emanuel, Ph.D.
Towson University
Dept. of ASLD
8000 York Road
Towson, MD 21252

Purpose of the Study:

Children who have difficulty with auditory processing sometimes have problems with language tasks such as following spoken instructions and understanding speech in difficult listening situations (e.g., a noisy classroom), even when they have good hearing and intelligence. The purpose of this project is to determine if new normative data (McDermott, 2014) is specific and sensitive enough to identify and diagnose auditory processing disorder.

Procedures:

If your child participates in this study, a series of assessments will be performed. This will involve two sessions lasting a total of approximately four hours. During these sessions your child will participate in a number of different listening, learning and language tasks. For some tasks your child will be asked to report back what they hear through earphones. Short breaks will be provided as needed during testing to avoid fatigue. These sessions will take place at the Hearing And Listening Lab (HALL) in Van

Bokkelen Hall at Towson University (Dr. Smart's research laboratory). Children usually enjoy the variety of listening games and activities so we anticipate that they will be excited about this study. But if, at any time, your child decides he/she does not want to participate the testing will cease immediately.

Risks/Discomfort:

There are no known risks for participating in this study. The tests included in this study are a part of routine clinical testing.

Benefits:

Comprehensive auditory processing evaluation, hearing screening, and screening for language, attention, and learning at no cost. The data collected during this research study will be used to further support the use of new normative data for the identification and diagnosis of auditory processing disorder.

Participation:

Participation in this study is voluntary. Your child is free to withdraw or discontinue participation at any time.

Compensation:

No compensation will be provided.

Confidentiality:

Participation in this study is voluntary. All information will remain strictly confidential. Although the descriptions and findings may be published, at no time will the name or identifying information of any participant be disclosed.

Please indicate whether or not you wish to have your child participate in this project, by checking a statement below and returning it to us in the enclosed self-addressed stamped envelope.

_____ I grant permission for my child, ____ to participate in this project.

_____ I do not grant permission for my child,____ to participate in this project.

_____ Affirmative agreement of child

____ _______________
Parent/Guardian's signature Date

Home address: ____

____

____

Home phone number: _______________________________________

Email address: ____

Upon receipt of this form we will call you to set-up an appointment.

_____________________________________ _______________
Principal Investigator's Signature Date

If you have any questions regarding this study please contact the Principal Investigator, Dr. Jennifer L. Smart, phone: (410) 704-3105 or email: JSmart@towson.edu or the Institutional Review Board Chairperson, Dr. Debi Gartland, Office of University Research Services, 8000 York Road, Towson University, Towson, Maryland 21252; phone: (410) 704-2236.

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY (PHONE: 410-704-2236).

Department of Audiology, Speech-Language Pathology,
and Deaf Studies

INFORMED ASSENT FORM

Project title: Testing for Auditory Processing Disorder in Children Using New Normative Values

Principal Investigators:
Jennifer L. Smart, Ph.D. and Diana C. Emanuel, Ph.D.
Towson University
Dept. of ASLD
8000 York Road
Towson, MD 21252

Information Sheet for Participants

(To be read aloud to each participant)

Purpose of study

You are participating in this study in order to help us gather information about auditory processing, or in other words, how we hear.

What tests does the study involve?

First of all, we will complete activities like pointing to patterns in a book, clicking the computer mouse any time you see an image on the screen, and pushing a button when you hear a beep. These activities will help us to learn more about your language, learning, hearing, and attention.

We will then play a series of listening games. We will play sounds like beeps or words to you through earphones. You will have to press a button or tell me what you hear. All of the sounds will be presented at a comfortable volume.

You can ask for a break at any time you need one.

Visits

You will come to see us two times at Towson University to complete the tasks I described. Each visit will last about 2 hours.

Child Assent Form

(To be read aloud to the child and signed by researcher if child agrees to participate)

Title of Project: Testing for Auditory Processing Disorder in Children Using New Normative Values

Primary Investigators: Jennifer Smart, Ph.D. and Diana Emanuel, Ph.D.

If you are happy to do this study, I will need you to write your name on this piece of paper. First, I will ask you some questions, just to make sure that you are happy to do this. Say 'yes' if you agree with what I am saying. If you do not agree with the statement, tell me 'no.'

- I have had the information sheet read out loud to me.
- I understand that you want to find out about my listening and how I hear sounds.
- I understand that I can decide to stop at any time.
- I understand that some of my answers will be used in a report, but that people reading the report will not know that the answers are mine, because my name will not be written on it.
- I understand that my answers will be kept for a long time in a safe place.
- I have had a chance to ask questions.

If you would like to do this, please write your name and I will sign below.

………………………………………………………
………………………………………………
Child's Name   Researcher's Signature

Today's date:……………………………………

If you have any questions regarding this study please contact the Principal Investigator, Dr. Jennifer L. Smart, phone: (410) 704-3105 or email: JSmart@towson.edu or the Institutional Review Board Chairperson, Dr. Debi Gartland, Office of University Research Services, 8000 York Road, Towson University, Towson, Maryland 21252; phone: (410) 704-2236.

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY (PHONE: 410-704-2236).

APPENDIX D

TOWSON UNIVERSITY

Office of Sponsored Programs
& Research

Towson University
8000 York Road
Towson, MD 21252-0001

t. 410 704-2236
f. 410 704-4494

APPROVAL NUMBER: 15-A039

To: Jennifer Smart
8000 York Road
Towson MD 21252

From: Institutional Review Board for the Proctection of Human Subjects Melissa Groves, Member

Date: Monday, January 26, 2015

RE: Application for Approval of Research Involving the Use of Human Participants

Thank you for submitting an Application for Approval of Research Involving the Use of Human Participants to the Institutional Review Board for the Protection of Human Participants (IRB) at Towson University. The IRB hereby approves your proposal titled:

Testing for Auditory Processing Disorder in Children Using New Normative Values

If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should your research extend beyond one year in duration, or should there be substantive changes in your research protocol, you will need to submit another application for approval at that time.
We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC: 3 Co-Pi's
File

TOWSON UNIVERSITY

Date: Monday, January 26, 2015

NOTICE OF APPROVAL

TO: Jennifer Smart **DEPT:** ASLD

PROJECT TITLE: *Testing for Auditory Processing Disorder in Children Using New Normative Values*

SPONSORING AGENCY: None

APPROVAL NUMBER: 15-A039

The Institutional Review Board for the Protection of Human Participants has approved the project described above. Approval was based on the descriptive material and procedures you submitted for review. Should any changes be made in your procedures, or if you should encounter any new risks, reactions, injuries, or deaths of persons as participants, you must notify the Board.

A consent form: [✓] is [ ] is not required of each participant

Assent: [✓] is [ ] is not required of each participant

This protocol was first approved on: 26-Jan-2015

This research will be reviewed every year from the date of first approval.

(for)

Melissa Groves, Member

Towson University Institutional Review Board

APPENDIX E

Department of Audiology, Speech Language Pathology and Deaf Studies
Towson University-8000 York Road-Towson, MD 21252-0001
Voice or TTY: 410-704-3105

CHILD CASE HISTORY FORM

Child's Name:____

Date of birth:_______________________Age: _______

Home Address: ____
____

Home phone: __________________Parent Work or Cell phone: __________________

Parent/Guardian names:____

School & Teacher:______________________________________Current Grade: ____________

Name of person filling out this form and relationship to participant:

____

I. BIRTH HISTORY

A. Pregnancy and Delivery:

1. Was pregnancy full term? Yes ____ No____
2. Were there any complications during the pregnancy *or* delivery? *Yes ____ No ____

   *If yes, please explain:

   ____

   ____

3. List all medications (prescription and Over The Counter) taken during pregnancy:

____

____

3. Delivery by Caesarian? Yes ____ No ____

B. Neonatal Period (check where appropriate):

1. Normal: Yes ____ No ____
2. Cyanotic (blue): Yes ____ No ____
3. Jaundiced: Yes ____ No ____
4. Neonatal Intensive Care Unit? Yes ____ No ____
5. Other complications? *Yes ____ No ____

*If yes, please explain:

____

____

What was the birth weight? ____lbs. ___oz

Were there any feeding problems? Yes ____ No ____

Was the baby's activity level: Average ____ Overactive ____ Underactive ____

II. DEVELOPMENTAL HISTORY

Development:

1. Motor Development: Normal ____ Delayed ____
2. Speech/Language Development: Normal ____ Delayed ____
   a. Child's primary (first) language? ____________________________
   b. Is the child fluent in any other languages? If so, please specify ___________
3. Handedness: Right ____ Left ____ Ambidextrous (both) ____
4. Does your child play any musical instruments? Yes ___** No___

   If yes, which instrument? __________________________

III. MEDICAL HISTORY

A. Major Childhood Illnesses:

Age

1. Mumps ___
2. Measles ___
3. Chicken Pox ___
4. Seizures ___

Allergies (medications, foods, seasonal, etc.) *Yes ____ No ____

If yes, please explain:____

____

B. Other diagnoses:

Has your child been diagnosed with any of the following disorders or difficulties? <u>If yes, please note specific diagnosis, date, and professional who made the diagnosis</u>. Thank you.

Hearing loss: Yes___ No ___ comments:______________________________

Dyslexia: Yes ___No ___ comments:______________________________
Reading disorder: Yes ___No ___ comments:______________________________

Learning disability: Yes ___No ___ comments:______________________________

ADD/ADHD: Yes ___No ___ comments:______________________________

Language Disorder: Yes ___No ___ comments:______________________________

Autism Spectrum Disorder: Yes ___No ___ comments:__________________________

Asperger Syndrome: Yes ___No ___ comments:______________________________

Anxiety Disorder: Yes ___No ___ comments:______________________________

Other:_______________

IV. OTOLOGICAL HISTORY

	Yes	No	How many?	Which ear(s)?	Age(s)
Ear infections:	___	___	________	_________	_________
Ears draining:	___	___	________	_________	_________
Chronic colds:	___	___	________		_________

Has the child had the following:

	Yes	No	Age(s)
Pressure Equalization (P.E.) Tubes?	___	___	_____

If yes, which ear(s): ________________________________?

Tonsillectomy? ____ ____ _____

Adenoidectomy? ____ ____ _____

V. AUDITORY PROCESSING DISORDER

A. Diagnosis: Yes______ No_______

a. If yes:

i. Date of Diagnosis:________________

ii. Professional who gave diagnosis: ______________

iii. Therapy: Yes________ No________

1. If yes, explain:

____

____

B. Suspected: Yes_______ No________

a. How were you referred for this study?

____

APPENDIX F

L.I.F.E[1]. UK
Listening Inventory for Education
Teacher Appraisal of Listening

Name   **Date**_________

School ___________   **Teacher**____

Classroom soundfield amplification trial yes/no   Length of trial: Weeks

Personal f.m. amplification trial yes/no   Length of trial: Weeks

Details of Amplification system used_________

Instructions: Read the statement below and then circle the score that best describes the behaviour of the child (or children). You should make a judgement as to whether or not the following behaviours are a cause for concern or not.

		Rating				
	In your opinion	*Very good* ←		*Satis-factory*	*Very Poor* →	
1	Following class directions					
2	Following individual directions					
3	Overall attention span					
4	On task behaviour					
5	Rate of learning (speed of following instruction)					
6	Involvement in class discussions (volunteers more, makes appropriate contributions)					
7	Contributes when working in a group					
8	Paying attention to multimedia (e.g. video, OHP)					
9	Willingness to answer questions					
10	Answering questions in an appropriate and relevant manner					
11	Amount of repair behaviour (this refers to asking questions, to teacher or peer, in order to clarify what is required)					
12*	Overall noise levels in the class while working in groups					
13*	Noise levels in the class during whole class teaching					

Additional Comments:

[1] Based on LIFE by Karen Anderson and Joseph Smaldino 1997

* Only appropriate for classroom soundfield amplification systems

APPENDIX G

TOWSON UNIVERSITY

Department of Audiology, Speech-Language Pathology, and Deaf Studies

Date:__________________________

Dear Parent/Guardian(s) of: ____

Below is a description of each test in the auditory processing test battery and the screening tests that were administered during the study, *Testing for Auditory Processing Disorders Using New Normative Values*, followed by a table with the summary of the results. The additional screening tests administered were used to identify potential weakness in the areas of nonverbal cognitive ability, language, phonological processing, and attention. A summary of the results are found below.

Monaural Low Redundancy Tasks

A monaural low redundancy task uses a speech signal that is degraded, which makes it more difficult to understand. Making speech sound "quick," or adding competing noise are easy ways to assess the listener's ability to use the remaining cues of the signal to achieve auditory closure when it is not as clear.

Time Compressed (45%) + Reverberation (0.3s) Speech Test: This test measures the patient's ability to process quick alterations to the incoming auditory signal. This specific test presents 50 words to each ear separately that have been compressed by 45% (45% of the original signal has been eliminated) and included a reverberation or "echo" time of 0.3 seconds.

Auditory Figure Ground (AFG): This test measures the patient's ability to separate the signal from the competing noise. This specific test presents 20 words in the right ear (test ear) followed by 20 words in the left ear (test ear) while simultaneously presenting multi-talker babble (noise) into the test ear. Two signal to noise ratios (SNR) were used: +8 dB (the signal was 8 dB greater than the competing noise), and 0 dB (the signal was at the same loudness level as the competing noise).

Dichotic Listening Tasks

A dichotic listening task presents a different acoustic signal to each ear simultaneously. Some dichotic tasks require the patient's attention to be focused on each signal presented to the right and left ear (integration), while other dichotic tasks require separated attention and focus on only the signal presented to the specified ear (separation). By presenting a signal simultaneously, dichotic listening tasks measure the patient's ability to integrate or separate the incoming auditory signal.

Dichotic Double Digits Test: This test measures the patient's ability to integrate the auditory signal heard in both ears. This specific test presents a set of 20 two-digit pairs to the right ear while simultaneously presenting a different set of 20 two-digit pairs to the left ear. The patient is instructed to repeat all four numbers that were heard. The digits include numbers 1-6 and 8-10.

Temporal Processing and Patterning Tasks

A temporal processing task measures the patient's ability to process an acoustic signal in a specified time domain. Some temporal patterning tasks measure the patient's ability to process two or more signals and identify the pattern whether it is frequency or duration specific (temporal ordering or sequencing), while some temporal processing tasks measure the patient's ability to identify the shortest interval of time between two acoustic signals (temporal resolution or discrimination).

Frequency Patterns Test (FPT) Test: This test measures the patient's temporal sequencing ability related to frequency. This specific test presents 15 patterns of three tones that vary by a low frequency and a high frequency to each ear separately. The patient is instructed to repeat the pattern that was heard by identifying the tones as "low" or "high". For example, a possible sequence is: high-high-low.

Duration Pattern Test: This test measures the patient's temporal sequencing ability related to duration. This specific test presents 15 patterns of three tones that vary by a short duration and a long duration to each ear separately. The patient is instructed to repeat the pattern that was heard by identifying the tones as "short" or "long".

Random Gap Detection Test (RGDT): This test measures the patient's temporal resolution ability. This specific test presents a series tones that sound similar to a "rain drop". The tones are separated by intervals of 2, 5, 10, 15, 20, 25, 30, and 40 msec. or have no interval (0 msec.). The patient is instructed to state if s/he heard one tone or two tones. Four subtests were administered using 500, 1000, 2000, and 4000 Hz tones. The shortest interval that is identified by the patient is his/her threshold for that specific frequency. An average threshold is calculated by averaging the threshold of the tested frequencies.

Sound Localization and Lateralization Tasks
A sound localization and lateralization task measures the ability to sort through incoming auditory information and separate competing noise from the desired signal.

Listening in Spatialized Noise- Sentences Test (LiSN-S): This test measures the patient's ability to separate sounds occurring in one direction from sounds occurring in another direction. The participant will hear sentences that are embedded in competing speech. The patient is instructed to repeat target sentences that are delivered at various angles in space. There were 30 sentences for each of the four conditions. Five practice items were presented, followed by the actual test. The participant repeated back the sentence(s) heard. The computer scored the test.

Screening Tests

Test of Nonverbal Intelligence, 3rd Edition (TONI-3)
This test was used as a screening tool and measures cognitive ability in a nonverbal environment. It assesses abstract/figural problem solving skills without the use of language for instruction, the test itself, and responses. Five practice items were presented, followed by the actual test. The test consisted of a total 45-items, but the testing was terminated when the participant missed three items (out of five). The participant pointed to one of the response choices that completed the pattern. The test was not timed and was scored and interpreted in accordance with the test manual.

Clinical Evaluation of Language Fundamentals, 4th Edition- Screening Test (CELF-4): This test is a 47-item screening measure of expressive and receptive language. It was used to identify children who may be "at risk" for a language disorder. The CELF-4 Screening Test is not a comprehensive language evaluation and was not used to diagnose children with a language disorder.

Comprehensive Test of Phonological Processing (CTOPP): This test was used as a screening measure, and assesses sound awareness and the ability to code phonological information to store it in short-term memory and to retrieve it from long-term memory. Practices items were given followed by the actual test. The participant provided a verbal response to the question s/he was asked. Testing was discontinued if the participant was unable to complete the practice items correctly.

Integrated Visual and Auditory Continuous Performance Test (IVA-CPT): This test measures auditory and visual impulsivity and attention and was used as a screening test for sustained attention ability. Practice items were given followed by the actual test. A randomized pattern of 1's and 2's were presented to the participant either through the auditory or visual modality. The participant responded by clicking a mouse only when s/he saw or heard the target number (i.e. "1").

Summary of Test Results

Test	Interpretation	__________Scores	Normative Scores
Monaural Low Redundancy			
Time Compressed + Reverberated Speech	Pass:_______________ Fail:_______________	Right Ear- Left Ear-	
Auditory Figure Ground +8 dB SNR	Pass:_______________ Fail:_______________	Right Ear- Left Ear-	
Auditory Figure Ground 0 dB SNR	Pass:_______________ Fail:_______________	Right Ear- Left Ear-	
Dichotic Listening			
Dichotic Double Digits	Pass:_______________ Fail:_______________	Right Ear- Left Ear-	
Temporal Processing			
Frequency Pattern Sequence	Pass:_______________ Fail:_______________	Right Ear- Left Ear-	
Duration Pattern Test	Pass:_______________ Fail:_______________	Right Ear- Left Ear-	
Random Gap Detection Test	Pass:_______________ Fail:_______________		<20 msec.
Sound Localization and Lateralization			
Listening in Spatialized Noise Sentences Test	Pass:_______________ Fail:_______________	Area(s) of Concern:	
Screening Tests			
Test of Nonverbal Intelligence, 3rd Edition	Pass:_______________ Refer:______________		≥80
Clinical Evaluation	Pass:_______________		

of Language Fundamentals, 4th Ed., Screening Test	Refer:_____________		
Comprehensive Test of Phonological Processing	Pass:_____________ Refer:_____________		
Integrated Visual and Auditory Continuous Performance Test	Pass:_____________ Refer:_____________		

Results from this study suggest that your child should be:

- Tested for APD by a licensed audiologist __________
- Seen by an Speech-Language Pathologist for comprehensive testing __________
- Seen by an educational psychologist for comprehensive testing
- Seen by a(n) _______________________________ for additional testing __________
- No further testing is needed at this time ___________

If you have any questions about the test results or this study, please feel free to contact the Principal Investigator, Dr. Jennifer L. Smart, phone: 410-704-3105, or email: JSmart@towson.edu.

____
Lauren Fong, B.S.
Co-Investigator

____
Jennifer L. Smart, Ph.D., CCC-A
Principal Investigator

APPENDIX H

Table 11

Individual Participant Test Scores for the Screening Tests (SusAPD/APD Group)

		CTOPP				IVA-CPT	
Participant	TONI-3	PA	PM	RN	CELF-4	IVA-A	IVA-V
001	108	91	103	97	21	113	114
002	96	94	94	97	23	113	111
003	98	94	94	106	18	48	100
004	96	88	118	106	24	38	68
005	104	85	106	133	22	74	83
006	115	103	118	94	31	76	82
008	89	100	100	115	26	100	101
009	92	94	59	88	18	83	88
010	88	94	88	91	21	111	109
011	102	100	106	103	27	101	92

Note. Test of Nonverbal Intelligence, 3rd Edition (TONI-3). Phonological Awareness (PA), Phonological Memory (PM), and Rapid Naming (RN) are the sub-tests of the Comprehensive Test of Phonological Awareness (CTOPP). Clinical Evaluation of Language Fundamentals, 4th Edition Screening Test (CELF-4). Integrated Visual and Auditory Continuous Performance Test (IVA-CPT). IVA-A (auditory condition). IVA-V (visual condition).

Table 12

Individual Participant Test Scores for the MLR, DL and TP Domains (SusAPD/APD Group)

	MLR		DL		TP	
Part	CRW R/L	AFG 8/0	DDT R/L	FPT R/L	DPT R/L	RGDT
001	80/52	7/11	97.5/92.5	93.33/93.33	80/86.67	5 ms
002	64/84	9/8	100/100	86.67/93.33	73.33/40	4.25 ms
003	60/76	8/10	95/82.5	80/66.67	40/60	2.75 ms
004	56/64	8/9	100/97.5	100/93.33	66.67/66.67	10.5 ms
005	84/80	8/9	95/90	46.67/33.33	13.33/13.33	Inconclusive
006	84/72	12/8	92.5/92.5	100/93.33	80/60	2.75 ms
008	64/80	12/6	100/97.5	86.67/93.33	53.33/73.33	10 ms
009	72/96	12/12	90/67.5	60/20	20/13.33	11.67 ms
010	80/60	8/8	97.5/92.5	46.67/40	46.67/40	Inconclusive
011	68/68	9/9	97.5/95	86.67/93.33	46.67/53.33	3 ms

Note. Participant (Part). Time Compressed and Reverberated Words, right/left ears (CRW R/L). Auditory Figure Ground (AFG), 8 dB Signal to Noise Ratio/ 0 dB Signal to Noise Ratio (8/0). Dichotic Digits Test, right/left ears (DDT R/L). Frequency Pattern Test, right/left ears (FPT R/L). Duration Pattern Test, right/left ears (DPT R/L). Random Gap Detection Test (RGDT). Milliseconds (ms).

Table 13

Individual Participant Test Scores for the LiSN-S Test (SusAPD/APD Group)

	LiSN-S				
Participant	LC-SRT	HC-SRT	TA	SA	ToT
001	0.6	-14.4	4.6	13.6	15.1
002	-1.2	-12.7	6.7	7.6	11.4
003	-1.3	-10.5	5.5	8.4	9.2
004	-1.4	-12.9	4.8	9.7	11.5
005	-1.9	-11.6	6.7	10	9.6
006	-1.2	-10.8	2.6	6.5	9.6
008	0.5	-13.2	6.5	12.8	13.7
009	0.9	-7.7	3.7	7.3	8.6
010	-0.8	-10.7	3.2	9.2	9.9
011	-0.8	-12.9	10.4	10.4	12.1

Note. Listening in Spatialized Noise- Sentences Test (LiSN-S): Low-Cue Speech Recognition Threshold (LC-SRT), High-Cue Speech Recognition Threshold (HC-SRT), Talker Advantage (TA), Spatial Advantage (SA), and Total Advantage (ToT).

Table 14

Individual Participant Test Scores for the Screening Tests (CG)

		CTOPP				IVA-CPT	
Part	TONI-3	PA	PM	RN	CELF-4	IVA-A	IVA-V
39	117	100	109	97	22	118	114
41	121	121	121	118	29	110	96
48	103	112	121	136	31	109	103
51	107	94	112	115	25	105	79
59	115	103	100	121	26	116	110
62	100	115	118	115	31	105	95
66	104	97	115	79	28	80	108
95	115	112	106	121	29	105	107
109	130	103	109	94	28	82	72
110	118	97	103	91	19	104	99
113	135	121	91	103	22	109	114
114	118	106	115	115	26	109	90
121	102	106	112	118	25	18	75
124	117	103	91	112	25	60	56
125	130	97	103	115	25	124	117
127	98	118	85	106	25	104	105
134	105	100	113	103	25	109	112
141	130	112	127	106	25	54	28
143	111	121	103	97	26	108	103
94	115	109	100	112	23	115	112

Note. Participant (Part). Test of Nonverbal Intelligence, 3rd Edition (TONI-3). Phonological Awareness (PA), Phonological Memory (PM), and Rapid Naming (RN) are the sub-tests of the Comprehensive Test of Phonological Awareness (CTOPP). Clinical Evaluation of Language Fundamentals, 4th Edition Screening Test (CELF-4). Integrated Visual and Auditory Continuous Performance Test (IVA-CPT). IVA-A (auditory condition). IVA-V (visual condition).

Table 15

Individual Participant Test Scores for the MLR, DL and TP Domains (CG)

	MLR		DL	TP		
Part	CRW R/L	AFG 8/0	DDT R/L	FPT R/L	DPT R/L	RGDT
39	78/80	7/12	100/95	100/93.33	73.33/73.33	2.5 ms
41	78/76	12/12	97.5/97.5	80/80	80/80	10 ms
48	82/80	12/10	100/100	100/86.67	100/100	6.25 ms
51	78/74	10/11	97.5/92.5	93.33/86.67	80/66.67	7.5 m
59	68/76	8/10	100/97.5	93.33/100	93.33/86.67	6.25 ms
62	78/78	12/9	97.5/100	93.33/93.33	86.67/80	3 ms
66	96/92	12/16	97.5/92.5	86.67/80	100/80	2.75 ms
95	76/76	10/8	95/97.5	100/100	100/100	5.5 ms
109	90/68	10/10	95/100	100/100	80/73.33	3 ms
110	58/56	9/6	90/92.5	80/86.67	46.67/60	3 ms
113	64/66	6/8	100/100	100/93.33	86.67/93.33	5.5 ms
114	60/56	10/10	95/87.5	80/80	73.33/80	3.5 ms
121	66/60	12/7	97.5/90	80/86.67	66.67/73.33	3.5 ms
124	56/56	6/8	90/90	80/80	66.67/80	2.75 ms
125	76/76	10/10	95/100	100/86.67	93.33/93.33	3.5 ms
127	58/58	9/8	85/62.5	100/93.33	53.33/53.33	2 ms
134	86/84	9/11	95/85	93.33/93.33	80/66.67	16.67 ms
141	80/80	9/11	100/100	46.67/46.67	46.67/40	8.33 ms
143	72/70	10/10	95/97.5	100/93.33	53.33/73.33	8.33 ms
94	74/76	12/12	97.5/97.5	100/93.33	100/93.33	5.67 ms

Note. Participant (Part). Time Compressed and Reverberated Words, right/left ears (CRW R/L). Auditory Figure Ground (AFG), 8 dB Signal to Noise Ratio/ 0 dB Signal to Noise Ratio (8/0). Dichotic Digits Test, right/left ears (DDT R/L). Frequency Pattern Test, right/left ears (FPT R/L). Duration Pattern Test, right/left ears (DPT R/L). Random Gap Detection Test (RGDT). Milliseconds (ms).

Table 16

Individual Participant Test Scores for the LiSN-S Test (CG)

	LiSN-S				
Part	LC-SRT	HC-SRT	TA	SA	ToT
39	-1.7	-12.5	5.9	8	10.8
41	-3.2	-12.3	1.8	7.2	9
48	-1.5	-11	7.4	8.4	9.5
51	-1.2	-13.5	5.2	9.3	12.2
59	-2.3	-11	3.2	7.5	8.7
62	-1.9	-14.6	5.9	9.7	12.7
66	-1.4	-12.6	5.1	15.1	11.2
95	-0.6	-13.7	8.4	14.9	13.1
109	0.8	-14	7.7	11.3	14.7
110	0.6	-14	5.5	11.6	14.7
113	-2.2	-12.8	5.5	11.1	10.5
114	-1.4	-12.2	3.8	8.7	10.9
121	-2.6	-12.9	5.9	11.4	10.2
124	-1.1	-12.7	8.1	7.6	11.6
125	-0.3	-11.3	6.6	7.9	11
127	-0.5	-11.9	6	10.5	11.4
134	0.2	-12.5	7.8	9.1	12.7
141	-1.1	-7.7	3	8	6.6
143	0.4	-14.8	8.2	13	15.2
94	-0.7	-12.5	4.8	7.2	11.9

Note. Participant (Part). Listening in Spatialized Noise- Sentences Test (LiSN-S): Low-Cue Speech Recognition Threshold (LC-SRT), High-Cue Speech Recognition Threshold (HC-SRT), Talker Advantage (TA), Spatial Advantage (SA), and Total Advantage (ToT).

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