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Auditory Processing Disorder: A Comparison of Traditional Testing Methods and New Technology

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Katherine Maffetone

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AUDIOLOGY DOCTORAL THESIS APPROVAL PAGE

This is to certify that the Audiology Doctoral Thesis prepared by Katherine Malfetone entitled: Auditory Processing Disorder: A Comparison of Traditional Testing Methods and New Technology has been approved by his or her committee as satisfactory completion of the Audiology Doctoral Thesis requirement for the degree Doctor of Audiology (Au.D.)

Diana C. Emanuel, Ph.D., CCC-A Co-Chair, Audiology Doctoral Thesis Committee	05/11/16 Date
Stephanie Nagle, Ph.D., Au.D. Co-Chair, Audiology Doctoral Thesis Committee	5/11/2016 Date
Jennifer L. Smart, Ph.D. Committee Member	5/11/16 Date
Andrea S. Kelly, Ph.D. Committee Member	5/5/2016 Date
Dr. Janet DeLany Dean of Graduate Studies	5-16-16 Date

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ABSTRACT

The validity and feasibility of auditory processing disorder (APD) diagnostic testing through a behavioral test battery has been well established. Auditory processing evaluation is known to be lengthy and tedious. Yet, research in the area of new technology such as engaging diagnostic computerized testing is lacking. The purpose of the present study was to conduct a pilot study and case descriptive analysis to examine the use of the Feather Squadron application or app. Ten children with suspected auditory processing disorder (APD), age 8 to 15 years and older, were recruited for an evaluation with traditional tests and on a new diagnostic tablet-based app, Feather Squadron. Four participants were excluded from data analysis due to confounding factors. Using an aggregate data set of six participants, the sensitivity and specificity were both 100 %. McNemar's tests indicated no significant difference of classification based on testing methods. Due to the small sample size and heterogeneous nature of APD, case studies were prepared to further examine the data.

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CHAPTER 1

Introduction

Auditory Processing Disorder (APD) is synonymous with auditory processing dysfunction. APD is a deficit in one or more auditory processes and can be simply defined, as a problem with interpreting auditory information when peripheral hearing is normal or near normal. Individuals with APD complain of difficulty listening in noisy environments and following multistep directions. APD can affect children and adults.

Auditory processing diagnosis is a rigorous and difficult task, because of the complexity of the disorder. It is especially difficult to diagnose when there are co-morbid disorders such as attention deficit hyperactivity disorder (ADHD), language delay, and learning disorders. There are many considerations, including test psychometrics, test administration, and patient factors, when conducting an auditory processing diagnostic evaluation. The feasibility of diagnosing APD through a behavioral test battery, and the validity of these tests, has been well documented and has become the traditional approach; however, research in the area of new technology such as application-based or app-based diagnostic testing is lacking. New technology such as app-based diagnostic testing has emerged. A recent publication by Barker and Purdy (2015) evaluated the application or app, Feather Squadron with normal control children and found the app to be correlated with diagnostic tests; however, the app has not been evaluated with children suspected of APD. Therefore, the present study was a pilot study (n=10) compared the diagnostic outcomes obtained by a tablet-based diagnostic app to the results obtained by traditional testing.

CHAPTER 2

Literature Review

Auditory Processing Disorder

Auditory processing refers to how the Central Nervous System (CNS), specifically the Central Auditory Nervous System (CANS), interprets auditory information through listening (American Speech Language Hearing Association [ASHA], 1996; Bamiou, Musiek, & Luxon, 2001; McFarland & Cacace, 1995). Auditory processes include sound localization and lateralization, binaural integration, binaural separation, temporal sequencing, temporal resolution, and auditory closure (ASHA, 1996, 2005a, 2005b; Chermak, 2002).

Auditory Processing Disorder is a deficit in one or more of these auditory processes and can be simply defined as a deficit in processing auditory information (ASHA, 2005a, 2005b; Jerger & Musiek, 2000; Noffsinger, Wilson, & Musiek, 1994b). This deficit can arise from any abnormality of the CNS that alters the perceptual processing of auditory stimuli (ASHA, 1996, 2005b; American Academy of Audiology [AAA], 2010; Bamiou et al., 2001). Dysfunction can occur anywhere in the auditory pathway (ASHA, 1996, 2005b; AAA, 2010; Bamiou et al., 2001).

Auditory Processing Disorder (APD), is also known as Central Auditory Processing Disorder (CAPD) and (Central) Auditory Processing Disorder ([C]APD). To avoid confusion, APD or Auditory Processing Disorder, will be the only term utilized in this paper (ASHA, 1996, 2005b; Jerger & Musiek, 2000). Even though ASHA (2005b) determined APD to be the most appropriate term because of the central origin of the deficit, the majority of recent literature and online resources utilize the term APD (Emanuel, Smart, Bernhard, & McDermott, 2013). According to Jerger and Musiek (2000) the word “central” can be misrepresentative because dysfunction can occur due to damage in the auditory periphery. Emanuel and colleagues (2013) emphasized the importance of consistency of terminology in attempt to phase out older or outdated terms to be consistent. Therefore, APD will be the term utilized for the rest of this paper.

Symptoms. APD is a listening problem, which becomes more apparent in difficult listening situations (Chermak, 2002). Individuals with APD usually struggle with understanding conversations in background noise and reverberant environments or when the speech is fast, degraded, or complex (Chermak, 2002; Jerger & Musiek, 2000). Difficulty following lengthy conversations and oral multi-step instructions are common complaints of individuals with APD (Chermak, 2002; Jerger & Musiek, 2000). Many individuals with APD have difficulty interpreting verbal messages, reading, and spelling (Chermak, 2002). Individuals with APD have trouble with phonological awareness and memory of verbal content (Chermak, 2002). Children with APD may present as inattentive or distracted when oral communication, like verbal directions, is delivered (Bamiou et al., 2001). Auditory processing deficits may appear in early school years or later on, when the acoustic environment changes or when curriculum becomes more rigorous (Bamiou et al., 2001).

Population /Prevalence. APD affects children and adults. The prevalence has been reported ranging from 0.5% to 10%, with boys being affected twice as much as girls (Nagao et al., 2016). Due to the manifestation of the auditory processing deficits in the classroom and learning implications, children are the focus of this study.

Etiologies. There are different hypotheses of the potential source of APD in the pediatric population. APD may have a definite anatomical cause such as stroke, brain trauma, or epilepsy. Conversely, there may be cases for which there is no clear physiological cause of APD; such is true of individuals with idiopathic or neuromaturational causes (Musiek, Gollegly, & Ross, 1985).

Musiek et al. (1985) hypothesized that the behaviors associated with APD may be due to a neuromaturational issue. In CANS maturation delay cases, it is possible that children will present with APD symptoms during the delayed period, but these complaints will lessen with aging over time (Musiek et al., 1985; Musiek, Gollegly, Lamb, & Lamb 1990b; Musiek, Kibbe, & Baran, 1984). In other cases, some authors have suggested that APD can be attributed to neuromorphological disorders primarily attributed to polymicrogyri, underdeveloped cells in the left hemisphere and auditory region near the corpus callosum (Boscario et al. 2009; Boscariol et al., 2011; Katz, 1968, Musiek et al., 1985; Musiek & Lee, 1998). If any of the CANS is affected, including areas like the insula, corpus callosum, or Heschl's gyrus, APD symptoms may be present; however, most pediatric APD cases have no brain abnormalities or lesions seen through medical imaging (Musiek & Lee, 1998).

Neurological disorders and trauma are thought to be less prevalent causes of APD (Musiek et al., 1985; Musiek & Lee, 1998). There are many medical conditions that have auditory processing symptoms; a medical physician should be consulted if symptoms include severe headaches (Musiek et al., 1985). Some conditions such as CANS tumors, cerebrovascular disorders, and epilepsy may cause children to have auditory processing complaints (Bamiou et al., 2001; Musiek & Lee, 1998).

Comorbidities. There are many connections between APD and language, learning disorders, and attention (Bamiou et al., 2001; Chermak, 2002; Gomez & Condon, 1999). Because of the complex nature of the brain and the relationships between auditory processing and other functions, APD may have numerous comorbidities (Bamiou et al., 2001; Chermak, 2002; Gomez & Condon, 1999).

Language-based disorders such as Specific Language Impairment (SLI) are linked to auditory processing deficits (Bamiou et al., 2001; Ferguson, Hall, Riley, & Moore, 2011; Loo, Bamiou, & Rosen, 2013). Ferguson and colleagues (2011) emphasized the consequences of APD and SLI in children. Through behavioral assessment and parental reports of children with SLI or APD, the authors identified that there was no difference between the scores of both groups of children on communication, listening, behavior, and cognitive assessments; thus, indicating major impacts on daily function and the similarity between the two diagnoses (Ferguson et al., 2011). When compared to normal functioning peers, the children with SLI and APD performed worse on both subjective and behavioral measures of cognition, language, literacy, and speech intelligibility (Ferguson et al., 2011). Based on these findings, Ferguson and colleagues (2011) concluded that there was high co-occurrence between SLI and APD and diagnosis must differentiate similar symptoms through subjective and objective measures by appropriate professionals.

Other disorders, like Learning Disabilities (LD), dyslexia or reading disorders (RDs), may have auditory processing issues because of the shared degraded temporal abilities (Bamiou et al., 2001; Gomez, & Condon, 1999; Sharma, Purdy, & Kelly, 2009; Tallal et al., 1996). In a study by Sharma et al. (2009), children with suspected or confirmed APD underwent several tests to assess for SLIs, RDs, and APD. The authors found that 47% of the children had scores that qualified them for all three diagnoses whereas only 4% had APD only. Ten percent of the children had both APD and SLI and 10% had scores that would qualify for a diagnosis of APD and RD, indicating the high co-morbidly of reading disorders, language impairments, and APD (Sharma et al., 2009). A similar study by Gomez and Condon (1999) found that APD was highly comorbid with both LD and Attention Deficit Hyperactivity Disorder (ADHD).

Another common comorbidity with APD is ADHD (Chermak, 2002; Chermak, Hall, & Musiek, 1999; Gomez & Condon, 1999). Because of the heterogeneous nature of APD and ADHD with all its subtypes, there is overlap and commonalities of symptoms between the two disorders (Cook et al., 1993; Chermak et al., 1999; Bamiou et al., 2001; Gomez, & Condon, 1999). Two commonalities between ADHD and APD are auditory inattention and distractibility, which may present in a variety of ways (Chermak et al., 1999; Gomez, & Condon, 1999).

Since children with APD struggle understanding oral language, especially in difficult listening situations with competing speech or background noise, they may say “huh” or “what” often, misinterpret oral messages consistently, or ask for frequent repetitions; therefore they may appear distracted, unfocused, or unaware (Chermak et al., 1999). Children with ADHD, specifically of the inattentive subtype, may have difficulty with sustained attention, attention to detail, follow through of instruction, initiation of difficult or multi-step tasks, and lack of focus to extraneous stimuli and in general is similar to the symptoms of APD. Chermak, Tucker, and Seikel (2002) stated the cause of these symptoms are extremely different: APD is a listening deficit and a perceptual disorder whereas, ADHD is cognitive disorder with poor executive functioning and self-regulation that comes across as attention issues.

Even though on the surface APD and ADHD may present similarly and can be co-morbid, the characteristics of each are visibly delineated by both diagnosing professionals (Chermak et al., 1999; Chermak et al., 2002). A study by Chermak and colleagues (2002) evaluated the opinions of pediatricians and audiologists in regards, to the behaviors of ADHD of the primarily inattentive type and APD. The authors sent surveys to professionals, to ranked 58 symptoms based on characteristics of either disorder (Chermak et al., 2002). Chermak et al. (2002) found physicians ranked the top two symptoms associated with ADHD of the inattentive subtype as inattention and academic difficulties; whereas audiologists ranked the top symptoms of APD as asking for frequent repetitions and poor listening abilities (Chermak et al., 2002). These symptoms are caused by two different problems. ADHD can be described as dysfunction in rule-governed behavior which causes symptoms that lead to issues with initiation, sustaining, inhibiting, or shifting attention whereas, APD is the breakdown of the comprehension of the content of oral speech in difficult listening environment (Chermak et al., 2002). Yet, some of the symptoms were linked to both diagnoses. Therefore, it is important to understand that ADHD and APD are two separate entities but can co-occur and cause similar manifestations. Proper professionals are needed to accurately diagnose and manage both disorders.

APD may be comorbid with many disorders making differential diagnosis difficult. Attention, language, cognition, memory, and speech may factor into test administration. For example, a child with ADHD may need frequent breaks due to problems with sustained attention (Cook et al., 1993). Children with speech or language delays should be evaluated with tests with low linguistic loads. Comorbidity may also influence recommendations and the tests utilized in the battery. It is important to note the heterogeneous nature of the population being assessed for APD.

Patient Factors

Assessment of APD is a very complex process due to the numerous structures of the brain and cognitive processes involved in auditory processing. Factors such as language abilities, cognition, and hearing status influence auditory processing and therefore affect the assessment process (Jerger & Musiek, 2000).

Language Status and Proficiency. Language –based disorders can be comorbid with APD (Bamiou et al., 2001; Ferguson et al., 2011; Loo et al., 2013). Speech and language abilities may also confound the performance and findings on APD tests that have a high language load or require a verbal response (Jerger & Musiek, 2000). For example, assessments that utilize complex speech stimuli may not accurately measure auditory processing skills, if the child does not have the appropriate speech and language skills. When language or speech is suspected to be disordered, the results of APD assessment should be interpreted with caution (Chermak, 2002).

Many of the assessments utilized in the APD behavioral test battery are normed on children whose primarily language is English. Non-native English speakers may not have the English language proficiencies needed for testing (Tabri, Chacra, & Pring, 2010). A study by Tabri and colleagues (2010) found that bilingual and trilingual children performed poorly in difficult listening environments such as in noise or in reverberant situations, when compared to their monolingual peers, indicating reduced speech perception. Therefore, assessment of non-native English speakers should include tonal stimuli and alternate responses (Chermak, 2002). APD assessments of multilingual speakers, non-Native English speakers, and those with language-based disorders should be administered and interpreted with caution.

Age Consideration. The difficult nature of APD testing on young children can be misrepresentative of auditory processing abilities (Chermak, 2002; Moncrieff, 2011). Children under the age of seven years should not be diagnosed with APD due to cognitive, language, and neurological maturation associated with aging.

Auditory processing abilities are dependent on the neuromaturation of the CANS and emerge with age (Moncrieff, 2011, 2015; Yathiraj & Vanaja, 2015). Development of the different auditory processing structures and maturation of the system is seen into adolescence (Neijenhuis, Snik, Priester, van Kordenoordt, & van der Broek, 2002; Yathiraj & Vanaja, 2015; Yoshimura et al., 2014). According to one study, neuromaturation does not become adult like until age 12 years (Yoshimura et al., 2014). Research by Cacace and McFarland (1992) and Moncrieff (2011) found that the participants under the age of seven had more varied scoring on APD testing that could be attributed to poor attention, memory, and language abilities associated with incomplete myelination of an immature brain. Therefore, due to the variability of development of the CANS that is seen until age seven, there is a minimum age requirement for APD evaluations (AAA, 2010; Cacace & McFarland, 1992; Moncrieff, 2011; Musiek et al., 1984; Neijenhuis et al., 2002; Yathiraj & Vanaja, 2015; Yoshimura et al., 2014).

Cognition. Cognitive capabilities are involved in auditory processing skills. Reduced cognitive function can negatively confound the results of an auditory processing assessment (AAA, 2010; Gyldenkærne, Dillon, Sharma, & Purdy, 2014; Tomlin, Dillon, Sharma, & Rance, 2015 Weihing et al., 2015). A listener's cognitive abilities must be considered prior to behavioral testing (AAA, 2010). A study by Tomlin and colleagues (2015) examined the relationship between cognition and pediatric APD test results. The authors found that poor cognitive abilities were associated with poor APD test results. Therefore, children with intellectual disabilities should not be evaluated for APD because results may not reflect auditory processing abilities, but reduced cognitive function (Gyldenkærne et al., 2014). Musiek and colleagues (1990b) stated that individuals with APD usually have normal to high intelligence.

Hearing Status. Hearing loss and Auditory Neuropathy Spectrum Disorder (ANSD) can cause symptoms similar to those of APD. In order to assess auditory status, an audiologic evaluation should be performed prior to administering an APD behavioral test battery (AAA, 2010; Bamiou et al, 2001; Miltenberger, Dawson, & Raica, 1978).

The AAA (2010) guidelines indicate that otoacoustic emissions or OAEs, immittance measures which include tympanometry and acoustic reflexes for both ipsilateral and contralateral stimulation, pure-tone audiometry, and speech audiometry should be performed prior to APD assessment. Emanuel (2002) surveyed audiologists to gain knowledge of what APD procedures are being utilized clinically. Out of 192 responses, the majority of audiologist performed an audiologic evaluation prior to central testing (Emanuel, 2002). All of the respondents at least performed pure tone audiometry and tympanometry prior to administering an APD test battery (Emanuel, 2002). All the tests in the recommended audiologic battery by AAA (2010) are crucial for differential diagnosis. Auditory status should be known prior to central testing and accommodations to test administration should be made for cases of hearing loss. However, according to the guidelines set forth by AAA (2010), a diagnosis of APD should not be made for individuals with hearing loss and poor word recognition in quiet.

Auditory processing abilities can be degraded with hearing loss (Chermak, 2002; Miltenberger et al., 1978; Musiek, Baran, & Pinheiro, 1990a; Musiek, Gollegly, Kibbe, & Verkest-Lenz, 1991). Hearing loss affects audibility and clarity of the signal. Because hearing loss impairs the peripheral system, the clarity of the message becomes degraded and word discrimination abilities are reduced (Roeser, Johns, & Price, 1972). Difficulty in noise and the implications of elevated thresholds may cause hearing loss to be confused with APD (Roeser et al., 1972).

Hearing loss may affect the scores obtained on APD assessments (Miltenberger et al., 1978). A study by Miltenberger and colleagues (1978) found that 77% of the participants in the study, adults with varying degrees and configurations of sensorineural hearing loss, would be diagnosed with APD based on their poor performance on the battery; 17% failed the competing sentences test, 24% failed the binaural fusion test, 21% failed the alternating speech test, and 80% failed the filtered words test. These findings indicate that hearing loss can play a role in the assessment of APD.

APD does not affect the peripheral system and hearing should be essentially normal (Jerger, Johnson, & Loiselle, 1988; Musiek et al., 1990b). A complete audiologic evaluation needs to be performed prior to administering any APD tests to ensure accurate diagnosis. Peripheral hearing loss and ANSD can exhibit similarly to APD and should be ruled out prior to APD assessment in order to gain an accurate representation of auditory processing abilities. Chermak (2002) stated that a mild degree of hearing loss should not prevent APD testing, but appropriate modifications of test administration and evaluation interpretations should be made due to the normative data and implications of hearing loss.

APD Assessment

Screening. Case history, screening tools, and functional measures may assist in test selection when creating the battery and making appropriate referrals and recommendations (Musiek et al., 1985; Musiek et al., 1990b). According to Musiek and colleagues (1990b), screening can be defined as the acquisition of “preliminary information about characteristics which may be significant to the health, education, or well-being of the individual” (p. 375).

APD screening tests are beneficial for gathering information about children who are likely or at risk for auditory processing deficits (AAA, 2010; Musiek et al., 1990b). The importance of screening for APD is to increase awareness of the disorder, potentially identify an underlying medical cause of auditory processing deficits, reduce the amount of fragmented diagnoses, prevent the psychological and emotional effects of APD, and assist with classroom accommodations (Musiek et al., 1990b). Screening differs from diagnostic testing in a few ways. Screening is intended for early intervention and identification of a potential problem (Frankenburg, 1974). Also screening tools can be administered by a larger population of people in a short duration of time, whereas diagnostic testing should be administered by appropriate specialty professionals and may be time consuming (Musiek et al., 1990b; Musiek et al., 1991). In the case of APD, screening may administered by audiologists or related professionals. Diagnostic assessment should be performed by pediatric audiologists with knowledge for the disorder (ASHA, 2005a). Even though a screening tool is not considered diagnostic, it must be a valid and reliable measure (ASHA, 2005b; Frankenburg, 1974; Musiek et al., 1990b; Musiek et al., 1991).

Electrophysiological Measures. Electrophysiologic assessment can be recommended for the assessment of APD (Jerger & Musiek, 2000; ASHA, 2005; AAA, 1994, 2010). Electrophysiologic measures such as Auditory Brainstem Response (ABR), useful in APD assessments.

Emanuel (2002) found that most audiologist administer electrophysiological tests when needed, but not in every APD evaluation. Less than 15% of the respondents reported a consistent use of electrophysiology in APD assessment (Emanuel, 2002). The most common measure employed was the ABR (Emanuel, 2002; Musiek & Chermak, 1994). An ABR is also valuable for differential diagnosis of ANSD. Emanuel (2002) indicated that other electrophysiology measures, such as MLR and CERPs, were rarely reported as part of the APD diagnosis process. Chermak (2002) indicated that an APD diagnosis is primarily based on a behavioral test battery and enhanced by electrophysiological measures. In most cases, electrophysiological measures are administered on a situational basis or to gain further information.

Behavioral Test Battery

Pediatric audiologists with APD experience should select and administer an APD behavioral test battery to children suspected of the disorder (ASHA, 2005a). According to ASHA (2005a), Bellis and Ferre (1999), and Chermak (2002), the battery approach should be utilized with tests that evaluate different auditory processes and have both tonal and speech stimuli. However, there is no set test battery. Musiek and Chermak (1994) argued that there was not a set test battery because testing should be customized for each patient's needs. Furthering the arguments of Musiek and Chermak (1994), AAA (2010) stated in its guidelines that the APD behavioral test battery should be shaped by the case history, auditory complaints, and child in question, with the audiologist governing and selecting the appropriate tests.

Diagnostic Criteria. According to Wilson and Arnott (2013), there are differences in classification of what constitutes a diagnosis of APD and the accuracy of diagnosis. For example, AAA (2010) defined a diagnosis of APD when there is "a score two standard deviations or more below the mean for at least one ear on at least two different behavioral central auditory tests" (p.22), whereas ASHA (2005a) does not clearly state whether one ear or both ears must fail in order to justify a diagnosis of APD. There are two main approaches to diagnosing APD in the U.S.: a score of three standard deviations below the mean on at least one test or a score of two standard deviations below the mean on at least two test (AAA, 2010; Musiek, Chermak, Weihing, Zappulla, & Nagle, 2011). It is important to note that changes in the diagnostic criterion alters the test battery efficiency (Musiek et al., 2011). Wilson and Arnott (2013) expressed that until a clear consensus on APD diagnostic critera, all diagnostic criteria should be explicitly stated. So, for the purpose of this paper, a score of two standard deviations or more below the mean for at least one ear for at least two behavioral tests constitutes a diagnosis of APD.

Test Materials. The materials and parameters utilized during testing can influence the outcome of the measures, especially for a very heterogeneous population such as like those with APD. There needs to be consistency in test administration, materials utilized, and diagnostic criteria. It is important to administer the test in the same manner (same presentation level, audiometer set-up, and instructions) as how the normative data was collected (Noffsinger et al., 1994b). Noffsinger et al. (1994b) emphasized the importance of consistency of test administration. Clinically, pre-recorded test items on compact audio discs (CDs) are utilized for APD testing (Noffsinger et al., 1994b; Wilson, 1993).

Test Response Mode. Due to numerous confounding variables including language, speech, memory, and attention, several authors have recommended utilizing "computer-controlled adaptive psychophysical procedures" (Jerger & Musiek, 2000, p.470) for APD assessment (Levitt, 1992; McFarland & Cacace, 1995).Traditionally, most APD tests require the listener to click a button or verbally respond. Some modifications of test response may be made but should be interpreted with caution and noted in the report (Chermak, 2002). Computer-based testing requires responses be made through a touchscreen computer or tablet. Adaptive testing refers to changes in test material based on the accuracy of the previous response (Levitt, 1992). Adaptive testing is based on an up-down technique; an example of this is threshold seeking in pure tone audiometry (Cacace & McFarland, 2013; Levitt, 1992). The test material is altered in some way based on the previous response. The up-down technique through adaptive testing is highly efficient and reliable when the parameters such as adaption level and acceptability of responses are determined (Levitt, 1992).

Test response mode can vary during APD assessment with button clicks, raising a thumb, verbal answers, or humming. New technology such as adaptive tablet-based testing is available and will be discussed in a later section. The population being assessed for APD is heterogeneous and may have many comorbidities or weaknesses. Each test being employed must be valid and be appropriate for the patient.

Test Psychometrics

The APD battery should be composed of highly valid tests which evaluate multiple auditory processes at different levels of the auditory pathways (Emanuel, Ficca, & Korczak, 2011). Emanuel and colleagues (2011) found that most audiologists involved in APD management and diagnosis are in fact employing evidence-based practices and tools validated by the literature. By utilizing a large diverse test battery, diagnostic error is greatly reduced (Musiek et al., 2011). However, not every auditory process must be included in the test battery for it to be valid (ASHA, 2005; Musiek et al., 2011). Test validity, efficiency, and reliability are important considerations for selecting the APD test battery (Emanuel, 2002).

Test Validity. Test validity refers to the accuracy of achieving the desired measurements. For example, APD tests will measure central auditory processing deficits. However, due to the complex nature of auditory processing, there is no gold standard of how to measure test validity in this heterogeneous population (AAA, 2010; Dillon, Cameron, Glyde, Wilson, & Tomlin, 2012).

Test Efficiency. Diagnostic value is contingent on the test efficiency of each test in the battery (Musiek et al., 2011). Efficiency is based on the specificity and sensitivity of a measure. Sensitivity is the rate of correct identification or true positive, whereas specificity is the rate of correct rejection or true negative (Musiek et al., 2011).

Test Reliability. Test reliability is an important consideration when selecting tests for an APD battery assessment (AAA, 2010; Jerger & Musiek, 2000). Test-retest reliability refers to test score consistency over different sessions (Theunissen, Swanepoel, & Hanekom, 2009).

The test-retest reliability of APD testing is influenced by many variables. If test materials are reused during reliability studies, the listener can learn because of previous exposure to the stimuli; this is called the learning effect (Theunissen et al., 2009). The subjective nature of APD assessment, behavioral factors such as motivation, attention, age, language abilities, and health status may influence the test-retest results (Theunissen et al., 2009). Lastly, the variability and etiology of APD may play a role in measuring reliability (Musiek & Chermak, 1994). Maturation of the CANS or possible deterioration associated with neurological disorders can make long term test-retest reliability difficult to measure (Musiek & Chermak, 1994). The literature on test-retest reliability of APD assessments is limited (AAA, 2010; Jerger & Musiek, 2000).

Specific Auditory Processes

There are many auditory processes involved in correctly understanding and perceiving an auditory message. APD may demonstrate dysfunction of any auditory process. APD tests can be separated into tests of dichotic listening, temporal processing, and monaural low redundancy. Under these categories, there are a variety of tests that assess different auditory processes.

Dichotic Listening Tests. Dichotic listening occurs when there are different signals presented to each ear simultaneously. The signals are usually similar in nature (Noffsinger, Martinez, & Wilson, 1994a). Broadbent (1954) described that the mechanisms needed to simultaneously attend to different auditory stimulus are more complex than listening to the same stimulus in both ears. The stimuli in dichotic listening tests can vary from numbers, nonsense syllables, words, and sentences (Fifer, Jerger, Berlin, Tobey, & Campbell, 1983; Meyers, Roberts, Bayless, Volkert, & Evitts, 2002; Musiek, 1983a, 1983b). Dichotic listening tests are sensitive to lesions of the cortex, brainstem, and corpus callosum (De Bode, Sininger, Healy, Mathern & Zaidel, 2007; Musiek et al., 1983a; Musiek & Weihing, 2011).

Dichotic listening tasks can be used to evaluate an individual's ability to attend to competing signals in different ways, such as binaural integration and binaural separation (AAA, 2010; ASHA, 2005a; Noffsinger et al., 1994a). Binaural separation refers to dichotic listening tasks when an individual must be able to attend to one of the signals while ignoring the competing stimulus. An example of a test of binaural separation is the competing sentences test when, the listener must repeat the desired sentence while ignoring the competing sentence (Musiek, 1984b). Binaural integration refers to dichotic listening tasks where an individual must be able to listen to both signals. The Dichotic Digits Test (DDT), the dichotic word test, the dichotic sentence identification test, and the Staggered Spondaic Word test (SSW) test are all assessments of binaural integration (Boscariol et al., 2011; Fifer et al., 1983; McDermott et al., 2015; Meyers et al., 2002; Musiek, 1983a; 1983b; Musiek & Chermak, 1994; Noffsinger et al, 1994b). Each of these binaural integration tests requires the listener to identify the stimulus in both ears. Deficits can occur in either process.

Temporal Processing Tests. Temporal processing tasks evaluate a listener's ability to organize and process time-related aspects of acoustic signals (Musiek et al., 1990a). Some temporal processing tasks assess a listener's temporal ordering and sequencing abilities in terms of signal duration or frequency (Bamiou et al., 2006). Others measure temporal resolution abilities or the shortest interval of time an individual can distinguish the difference between two acoustic signals (ASHA, 2005a). Temporal resolution indicates the ability of the CANS to detect and respond to changes in the acoustic changes of the signal (Shinn, Chermak, & Musiek, 2009).

Tasks that assess temporal ordering and discrimination are the Frequency Pattern Test (FPT) and the duration pattern test (Musiek, 1994, 2002; Musiek et al., 1990a). These tests require the listener to distinguish the differences of the triad of tones and identify the pattern (i.e. in terms of frequency, low or high, or duration, short or long) by humming or verbally labeling the pattern.

Temporal resolution can be evaluated by gap detection tasks such as the Gaps in Noise test (GIN) and the random gap detection test (Dias, Jutras, Acrani, & Pereira, 2012; Musiek, Shinn, Jirsa, Bamiou, Baran, & Zaida, 2005; Shinn et al., 2009). The GIN requires the listener to detect gaps in noise monaurally, which may sound like a hiccup or break in the static noise (Musiek et al., 2005; Shinn et al., 2009). Temporal resolution is thought to be the basis of many auditory processes and skills such as speech perception and reading (Musiek et al., 2005; Shinn et al., 2009). Tests of temporal processing are sensitive to cortical lesions, corpus callosum lesions, and brainstem lesions (Musiek & Chermak, 1994; Noffsinger et al, 1994b).

Monaural Low Redundancy Tests. Monaural low redundancy tests demonstrate a listener’s ability to understand the verbal message under unfavorable listening conditions, such as noise, reverberation, and alterations to the clarity of speech (ASHA, 2005a). Monaural low redundancy tests refers to test material comprised of speech signals that have been degraded in some way (frequency, intensity, and temporal characteristics) making the message difficult to understand. Speech is redundant and the CANS makes judgments in order to comprehend the signal. The auditory process known as auditory closure is the discrimination ability that allows the message to be understood even though part of the signal is distorted or unclear. The redundant nature of speech is altered and auditory closure allows missing speech cues to be filled in. The filtered words test, the time compressed speech tests, and speech in noise tests all assess the listener's auditory closure ability (Musiek et al., 1985). The filtered words test and the time compressed speech test have alterations to the speech stimuli in terms of frequency and timing respectively (Bornstein, Wilson, & Cambron, 1994; Wilson, Preece, Salamon, Sperry & Bornstein, 1994). Monaural low redundancy tasks are sensitive to brainstem and cortex lesions (Musiek & Chermak, 1994).

Traditionally, APD is assessed using the previously mentioned tests which are recorded material that are played back through the audiometer. The CDs can be expensive, especially when multiple CDs are needed to create an appropriate battery based on the child. Additionally, the traditional assessment requires a CD player and an audiometer, which is another expense. Assessment of APD can also be tedious; test administration and scoring can vary (Dawes & Bishop, 2009). The validity of the test batteries have varied based on which tests are included (Musiek et al., 2011; Weihing et al. 2015). In the past ten years, there has been research in areas of new technology such as computerized testing (Cacace & McFarland, 2013; Given, Wasserman, Chari, Beattie, & Eden, 2008; Loo, Bamiou, Campbell, & Luxon, 2010; Sharma, Purdy, & Kelly, 2012; Rouse & Krueger, 2004; Stevens, Fanning, Coch, Sanders, & Neville, 2008; Yeung, Javidnia, Heley, Beauregard, Champagne, & Bromwich, 2013). More recently, an app-based diagnostic program by Acoustic Pioneer was developed to streamline the APD assessment (Barker and Purdy, 2015). With the development of an app-based assessment tool the costs are contained to the table (iPad), headphones, and Feather Squadron application or app and the test administration is standardized.

New Tests and Technology for the APD Assessment

In order to simplify APD diagnostic testing, new technology administered through an app via a tablet was developed. The Acoustic Pioneer app, Feather Squadron claims to diagnose APD in an easy and fun way (Barker & Purdy, 2015). Barker and Purdy (2015) investigated the validity of the Feather Squadron diagnostic app. It is important to note that one of the authors is a partial owner of Acoustic Pioneer and has a disclosed a financial interest. The authors examined the calibration of the app set-up with the recommended headphones (Koss UR10), test methods used in the app, the normative data utilized in the app, the app's subtests, and the comparison between traditional APD tests and the diagnostic assessment of the app.

A cross sectional design was employed with two experiments (Barker & Purdy, 2015). For the first experiment, normative data was collected with Group 1 (n = 899). A second group (Group 2) of normal individuals (n = 46) was used for the next experiment which evaluated test-retest reliability of the app in comparison to traditional APDs tests. The participants in the study were recruited from schools in New Zealand. Teachers and school tutors administered all of the testing; however, the authors do note that only audiologists can make a diagnosis of APD. The exclusion criteria included the following; English as a second language, diagnosis of speech and/or language disorder, inability to complete the lateralization subtest of the app, Type B or Type C tympanograms, hearing loss greater than or equal to 25 dB HL. Fifty-two of the 899 children recruited for Group 1 were excluded based on one or more of the exclusion criteria. The breakdown of the number of participants for each group are displayed in Table 1. The authors indicated that no diagnostic audiologic testing was performed, no case histories were provided, and no referrals for other professionals including, speech language pathologists and educational psychologists were made; it is unclear how the authors ensured that the participants did not have other disorders (Barker & Purdy, 2015).

Pre-test set-up considerations. For the collection of normative data, all the testing of Group 1 was performed in a quiet room of a school without any visual or auditory distractions (Barker & Purdy, 2015). For the second experiment, testing was administered in a separate building of a school. Ambient noise was measured prior to testing in the empty classrooms; noise did not exceed 30 dBA SPL. Five iPads were utilized for the study. The authors reported that the headphones selected to use with the app provide a reliable output in comparison to traditional TDH-39 headphones with a 2 dB or less variation at any frequency across the iPads (Barker & Purdy, 2015).

Testing. The app uses adaptive test techniques with a forced choice paradigm. According to Barker and Purdy (2015), the forced choice paradigm indicates that the assessment session does not continue until the child responds by touching the tablet.

Table 1

Number of participants recruited in the study by Barker and Purdy (2015)

Age	Number of Participants	
	Group 1	Group 2
5	100	4
6	103	6
7	93	9
8	85	5
9	88	6
10	92	4
11	169	8
12	148	3
13	21	0
14	0	1
Total	899	46

Note. For Group 1, 52 participants were excluded based upon the previously discussed criteria.

There were two sets of test administered to the participants. One set of tests which consisted of linguistic stimuli only was administered to the 5-7 year old group whereas, the complete diagnostic assessment (linguistic and non-linguistic stimuli) was administered to the 8 years and older group. This difference in test protocols was due to the report that 30% of preliminary sample in the 5-7 year age range were unable to perform the non-linguistic tasks (Barker & Purdy, 2015). The complete diagnostic assessment of the Feather Squadron app includes eight subtests (Table 2).

Subtests of Feather Squadron. There are eight games included in the diagnostic assessment of the Feather Squadron app (Barker & Purdy, 2015). Six of the subtests of the app are similar to some of the traditionally utilized APD tests (TU-APD). These six subtests of the Feather Squadron app will be referred to as the new technology APD test battery (NT-APD). The subtests utilized in the NT-APD that are similar to the TU-APD are described below.

Tonal pattern memory. Whistle Code Breaking game assesses tonal pattern memory (Barker & Purdy, 2015). The Whistle Code Breaking is a binaural activity, which the child must decipher the pattern of tones presented by the birds. The game display has birds that represents different pitches, 365 Hz, 999 Hz, and 2014 Hz. First, two birds are presented that play two pitches. The child must correctly identify the 2-tone pattern (i.e., high-low). The child responds non-verbally by selecting the birds that correspond to the high or low sounds in the order that the pattern was presented. The next level has the same two birds but this time they present a three-tone pattern (e.g., high-low-high).

Table 2

Summary of Auditory Processing Assessments for 8–14 Year-Old Children

Name of Test	Skill Assessed	Comments About Test	Area of Testing
Lateralization and Detection	Lateralization ability tested near the frequencies of 500, 1000, 2000, 4000 Hz	Tested first at 20 dB, or if failed then at 50 dB, or 30 dB then 50 dB for the lowest frequency	Non-linguistic
Tonal Pattern Memory	Auditory memory using non-speech stimuli	Four stages increasing in difficulty using tones	Non-linguistic
Tonal Speed	Temporal resolution using ability to follow pitch	Tones near 1000 and 2000 Hz	Non-linguistic
Tonal Dichotic	Dichotic ability using non-linguistic stimuli	Changes in duration to increase difficulty	Non-linguistic
Word Memory	Auditory memory	Used single-syllable numbers	Linguistic
Word Speed	Auditory closure using compressed speech in time	Used single-syllable color names as stimuli ad changed compression until threshold was found	Linguistic
Word Double Dichotic	Dichotic ability using speech stimuli	Used two single-syllable numbers per ear and given a percentage correct	Linguistic
Speech in Noise (Subtests 1 and 2)	Ability to follow speech in noise without (subtest 1) and with (subtest 2) release from masking cues	A threshold search method altering the noise level to identify two single-syllable target words	Linguistic

Note. Modified and used without permission from “An initial investigation into the validity of a computer-based auditory processing assessment (Feather Squadron)” p. 4, by M. D. Barker & S.C. Purdy.

Even more challenging than the first two tasks, the next task presents a third bird (or medium tone). Now the child must identify a pattern from the three tones (e.g., high-medium-low). The last stage includes the three birds that present patterns. If the child can correctly identify the three stimuli pattern, the pattern sequence increases by one bird tone; it continues to increase until the child incorrectly labels two patterns. On the summary page, there is a Tonal-Pattern Temporal Processing score and a Tonal Pattern-Memory score both of which are displayed in the non-linguistic stimuli area (Barker & Purdy, 2015).

Tonal speed. The category of tonal speed represents scores obtained in the Speed Whistles game (Barker & Purdy, 2015). The iPad display shows two birds which correspond with the frequencies, 999 Hz and 2014 Hz. The two birds whistle in a sequence and the child identifies the order of the whistles (i.e., high-low, low-high, same). The whistles are presented binaurally. The gap between the tones and the tone durations shorten as the game progresses. The duration starts at 500 ms and decreases to 2 ms over the course of the game. The shortest duration which is correctly identified two times out of three presentations is the threshold. The Speed Whistle results are displayed under the Rapid Tones category on the summary page under the non-linguistic stimuli area. Barker and Purdy (2015) described the Speed Whistles game as a cross-channel gap detection measure.

Tonal dichotic. For the tonal dichotic measure the child will see three birds on either side and hear two different whistles. One whistle will present in each ear but will present simultaneously. The child is tasked with selecting a bird on the side that corresponds with the whistles heard. The tones become more overlapped with each presentation, “becoming more dichotic by 20% increments” (Barker & Purdy, 2015, p. 5). However, when looking at Feather Squadron and the reports generated by the app, the game described in the Tonal Dichotic section is the most similar to the Double Animal Sounds (Barker & Purdy, 2015).

It is important to note that despite this recent publication, the stimuli used in the current version of the app are different than what was reported in the study. In another game, Double Animal Sounds, the child sees a frog, sheep, dog, bird, pig, bee, cat, and monkey. The child hears two animal sounds, one in each ear, presented simultaneously and the child is instructed to select the two animals who made the sound. The second level, presents four animal sounds, two sounds per ear. Scoring is recorded by percent correct per ear (Barker & Purdy, 2015). The report contains the scores per ear in the Double Animal Sounds game section.

Word Speed. The iPad display for the Word Speed section has seven birds of different colors (blue, brown, green, white, pink, red, grey, and black). The child hears the name of one color in one of their ears and is instructed to select the bird of that color (Barker & Purdy, 2015). As the game progresses, the auditory stimuli becomes more compressed. A threshold is determined when the person gets two of three presentations correct. This game is called Speed Codes and on the summary page of the report, it is the Rapid Speech score under the linguistic area.

Word Double Dichotic. The Word Double Dichotic game is the Double Codes game in the diagnostic assessment of the Feather Squadron app. The iPad display has birds with numbers 1-10 on them, excluding the number seven. The child hears two numbers, one number is presented to each ear simultaneously. The child is instructed to select the birds s/he hear that have the corresponding numbers. The scores for the Double Codes game corresponds with the Dichotic-double words under the linguistic area on the summary page.

Speech in Noise. The speech in noise game is Target Practice. The display shows a rainforest environment with different animals in it. The child is directed to select the animal, the speaker describes (i.e, blue dotty). The practice items do not have noise in the background (Barker & Purdy, 2015). The task increases in difficulty when a combination of broadband nature noise is presented in the background with no inter-aural timing or intensity cues provided. A score is generated when the child correctly selects the animal described at the lowest signal-to-noise ratio (Barker & Purdy, 2015). The final stage of the speech in noise game adds a localization component. A score for this task is calculated based on the child's ability to accurately choose the animal described. The speech in noise game has three scores on the report, without localization cues, with localization cues, and improvement with localization cues; the summary portion under the linguistic areas contains two scores: Speech-In-Noise (without localization cues) and Speech-In-Nosie (with localization cues).

Scoring. Following the assessment, scores are calculated by the Acoustic Pioneer app. The clinician can then access the report with scores from the Acoustic Pioneer website for a fee (www.acousticpioneer.com). The professional report consists of a summary page, which includes overall classification of skills, and a breakdown of scores by tests. The reports provides the test scores, number of standard deviations (SD) from the age-normed mean, and classification of the score (i.e., normal, mild, or significant). The classifications use the following criteria: normal result (>-1.0 SD), mild weakness (-

1.0 SD to -1.9 SD), and significant weakness (≤ -2.0 SD) (M. Barker, personal communication, March 8, 2016).

Traditional APD Test Comparison

Barker and Parker (2015) examined the scores obtained by the Feather Squadron app and three TU-APD tests for Group 2. The three traditional tests used for comparison were DDT, FPT, and the NU-6 Compressed (60%) and Reverberated Words (CRW-60) test. The TU-APD tests were administered via iPad under headphones at 50% of the volume (Barker & Purdy, 2015). The FPT was administered binaurally and the CRW-60 test was administered monaurally. Of the 48 children in Group 2, the FPT test was not administered to children age 7 years or younger, therefore only 27 of the participants were evaluated with all the NT-APD and TU-APD. The comparisons between the NT-APD and the TU-APD used by Barker and Purdy (2015) are displayed in Table 3.

Results indicated a significant low-moderate correlation for six of the seven areas (Barker & Purdy, 2015). The authors repeated testing seven days after initial testing to calculate test re-test reliability. Based on Wilcoxon matched pairs comparisons, the authors suggested equal test re-test reliability with the NT-APD when compared to the TU-APD tests (Barker & Purdy, 2015).

The authors discussed the benefits of the app: easy to administer, time-effective, reliable, and feasible. Barker and Purdy (2015) acknowledged that further evaluation of the NT-APD is needed to evaluate children diagnosed with APD and in conjunction with imaging studies to fully comprehend the auditory pathways and the deficits associated with APD.

Table 3

Test Pairing Utilized in Barker & Purdy (2015)

Traditional Test	Acoustic Pioneer Test
DDT	Double Codes
CRW-60	Speed Codes
FPT	Whistle Code Breaking

Purpose of This Study

The feasibility and validity of the traditional APD behavioral test battery has been well documented; however, research in the area of new technology such as app-based diagnostic testing is lacking. Only one recent publication by Barker and Purdy (2015) examined the Acoustic Pioneer diagnostic app, Feather Squadron. The purpose of the present study was to compare diagnostic outcomes obtained by the Acoustic Pioneer app to those obtained by the standard APD behavioral test battery for the pediatric population, age eight to 17 years, with suspected APD or listening complaints.

CHAPTER 3

Methodology

Participants

Ten children aged eight years to 17 years with listening concerns or suspected APD were recruited for participation through the auditory processing evaluation waitlist at the Towson University Hearing and Balance Center (TU HBC), referral, flyers, and word of mouth. Prior to scheduling an appointment for participation, the parent or guardian was asked about other diagnoses, listening concerns, and current accommodations. Prior to the beginning of testing, Towson University Institutional Review Board (IRB) approved informed consent and assent was obtained. A case history form (Appendix A) was completed by the parent or guardian of each participant. The completed forms were reviewed before testing of each participant.

Procedures/Materials

Testing was performed in either one or two sessions in a sound treated booth in Van Bokkelen Hall at Towson University. The materials and equipment utilized included a Grason Stadler (GSI) 61 two-channel diagnostic audiometer, Eartone 3A insert earphones, Tympstar immittance bridge, patient push button, Sony CD player, ILO OAE equipment, iPad, and Koss UR10 headphones. The GSI 61 audiometer and Tympstar bridge were calibrated according to American National Standards Institute (ANSI) standards (ANSI, 2010).

Audiologic evaluation. An audiologic evaluation consisting of otoscopy, pure-tone audiometry, speech audiometry, immittance testing, and Transient Evoked Otoacoustic Emissions (TEOAEs) were administered prior to central testing.

Tympanometry was performed using a 226-Hz probe tone. Ipsilateral and contralateral Acoustic Reflex Thresholds (ARTs) were obtained at 1000 Hz for both ears. ARTs of less than or equal to 95 dB HL were considered consistent with pure tone thresholds for both ipsilateral and contralateral stimulation (Gelfand, Schwander, & Silman, 1990). Immittance testing was performed utilizing a GSI Tympstar.

TEOAEs were assessed bilaterally from 1000 to 4000 Hz using ILO OAE equipment. Robust responses were defined as a signal to noise ratio (SNR) response amplitude greater than 3 dB at 1000 Hz or 6 dB from 1400 to 4000 Hz. TEOAEs were considered present when three of the six frequencies tested elicited robust responses in that ear. If a participant had reduced to absent TEOAEs, Distortion Product Otoacoustic Emissions (DPOAEs) were obtained.

Pure tone audiometry was performed using Eartone 3A insert earphones and the GSI 61 audiometer from 250 Hz to 8000 Hz in octave bands. Normal hearing was defined as a threshold of 15 dB HL or better for both ears at all frequencies tested. Speech Reception Thresholds (SRT) using recorded male spondaic words and Word Recognition Scores (WRS) using the Central Institute for the Deaf-22 (CID W-22) word lists (at 40 dB SL SRT) were obtained bilaterally. Audiologic testing was completed utilizing conventional techniques and a push button.

Cognitive screening. The Test of Nonverbal Intelligence (TONI-3) was administered prior to any central testing. Scoring was performed as per the test manual. All of the participants had age-appropriate nonverbal intelligence as per a deviation quotient score or scaled score of 80 or greater.

APD Traditional Testing

For the standard behavioral test battery, the DDT, FPT, GIN, time compressed speech at 45% compression with reverberation (CRW) test, SSW test and a speech in noise test was administered (Table 4). The speech in noise test utilized was the CID W-22 Word List +8 dB SNR with Multi-talker Babble. The starting ear was randomized. Breaks and encouragement was provided as needed for each participant. Test instructions was provided by the examiner and were altered based on participant's understanding. Prior to testing, all test stimuli were calibrated to the audiometer utilizing a tone which peaks at 0 on the VU meter. Test response mode and scoring were performed in accordance with the test manuals.

Scoring. A score was considered abnormal when it was two or more standard deviations below the age-appropriate mean. If two abnormal scores were obtained utilizing the traditional testing method, the participant was classified as having APD. If desired by the parent or guardian, a full diagnostic report with recommendations was supplied to the participant and family. All results and reports were reviewed and approved by a licensed audiologist.

APD App-Based Testing

For the Acoustic Pioneer portion, an iPad, the U.S. version of the Feather Squadron app, and Koss UR10 headphones were utilized. Testing was performed in a sound treated booth with the headphone volume at 50% as per the app instructions (Barker & Purdy, 2015). All subtests of the diagnostic assessment was administered.

Table 4

Test Pairing for the Present Study

TU-APD Test	Auditory Process Category	Presentation Level	References	NT-APD Test Correlate
DDT	Dichotic Listening	60 dB HL	McDermott et al., 2016	Double Animal Codes
SSW Test	Dichotic Listening	50 dB SL SRT	Katz, 1968	Double Codes
FPT	Temporal Processing	60 dB HL	McDermott et al., 2016	Whistle Code Breaking
GIN Test	Temporal Processing	50 dB SL SRT	Musiek et al., 2005; Shinn et al., 2009	Speed Whistles
CRW Test	Monaural Low Redundancy	60 dB HL	McDermott et al., 2016	Speed Codes
Speech in Noise Test	Monaural Low Redundancy	50 dB SL SRT & 58 dB SL SRT	Dubno et al., 1984	Target Practice (without localization cues)

Scoring. The scoring of the Feather Squadron was previously described. Not all the scores were utilized for comparison to the traditional counterpart (Table 4). A score was considered abnormal (i.e., significant weakness) when it was two or more standard deviations below the age-appropriate mean. If two abnormal scores were obtained utilizing the computerized testing method, the participant was classified as having APD.

Double Animal Codes and Double Codes have individual ear scores and an overall score (dichotic double-words and dichotic double-sounds, respectively) on the summary page of the report. The overall score was a mild weakness if one or both of the ear scores were a mild weakness; the overall score was a significant weakness if one or both of the ear scores were a significant weakness. Since the Double Animal Codes and Double Codes tests have two scores, the summary page overall test results, dichotic double-words and dichotic double-sounds, will be utilized for analysis. Because Speed Whistles, Whistle Code Breaking, and Target Practice were administered binaurally, these tests only have one score and not individual ear scores (Barker & Purdy, 2015).

Analysis

Analyses were primarily descriptive. Data were analyzed in two age groups (8 to 12 years and 13 to 17 years) due to the fact that neuromaturation becomes adult-like around age 12 years (Yoshimura et al., 2014). McNemar's tests were utilized to assess if there was a difference in the proportion of participants classified as disordered using the two different methods: the traditional battery approach and the computer-based approach (Table 4). A thorough review of the data were performed and case studies were prepared for several of the participants.

CHAPTER 4

Results

Participants

Ten children (five male and five females) with listening concerns or suspected APD were recruited for participation. The age ranges of the participants were 8 years, 1 month to 15 years, 0 months, with a median age of 10 years, 8 months. All participants lived in Maryland. Seven of the 10 participants were recruited from the TU HBC auditory processing evaluation waitlist, one participant was recruited through a referral from an outside audiologic facility, and the remaining participants were recruited through word of mouth. There were additional parents/guardians that expressed interested in participating in the study but did not meet the study criteria as assessed through initial contact via phone (i.e., low cognitive abilities or severe hearing loss). Nine of the participants completed the testing during one testing session. One participant required two test sessions due to participant fatigue on day 1.

Case history and screenings. Displayed in Table 5 is the delineation of reported current diagnosis by participant number. History of chronic otitis media was reported by parents or guardians of two participants. One participant was reported to be bilingual with English as the current dominant language. Eight of the ten participants had an Individualized Education Plan (IEP) in place or received IEP-like accommodations, as displayed in Figure 1. IEP-like accommodations signified that the participant or the parent requested an accommodation from the teacher (including preferential seating, second-chance learning, and peer help) even though a formal IEP was not in place.

Table 5

Delineation of Reported Diagnosis

Participant Number	ADHD	Speech or Language Disorder	LD	Lyme disease	ASD
1		X			
2					
3*					
4*		X			
5*					
6				X	
7	X	X	X		
8					
9					
10*	X	X			X

Note. X indicates positive diagnosis as per parental report, ADHD indicates Attention Deficit Hyperactivity Disorder, LD indicates learning disability, ASD indicates Autism Spectrum Disorder which includes previous diagnosis of Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS), and *indicates participants not included in aggregate data analysis.

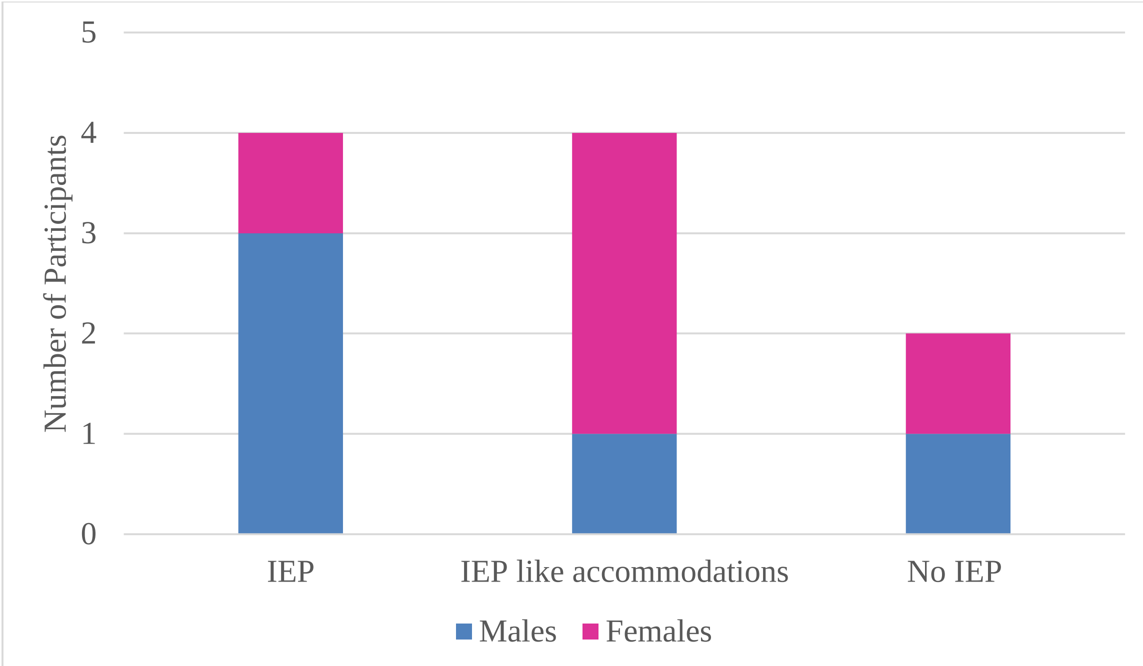

*Figure 1.*Participants receiving accommodations either through a formal IEP, informal IEP (IEP like accommodations), or no accommodations.

All 10 participants passed the cognitive screener (TONI-3) with a scaled score of 80 or greater. One participant (Participant 4) was excluded from the study due to the severity of his known language disorder. When screened with the Clinical Evaluation of Language Fundamentals-4 (CELF-4) screening test, he did not pass and therefore, APD testing could not be performed.

Audiologic evaluation. All of the remaining nine participants had type A tympanograms and unobstructed ear canals (Jerger, 1970). The results for ARTs and TEOAEs are displayed by Table 6. Pure tone thresholds were within normal limits for eight of the nine participants. Participant 5 had air conduction thresholds in the mild to moderate hearing loss range which was in disagreement with the participant's normal objective data. The inconsistency between subjective and objective testing warranted further audiological evaluation, therefore this participant was excluded from the aggregate data analysis.

APD Testing

Participant 10 was diagnosed with Autism Spectrum Disorder (ASD), a language-based disorder, and ADHD. He could not complete the TU-APD battery therefore he was excluded from the aggregate data analysis. Participant 3 was difficult to test, reliable results required modifications to the traditional test methods (e.g., pure tone testing was performed twice in order to obtain reliable results). Additionally, APD testing had to be performed at an elevated level due to participant request. These two factors made his results unreliable therefore Participant 3 was excluded from further data analysis.

Table 6

ART and OAE Results by Participant Number

Participant Number	ARTs				OAEs			
	Contralateral Stimulation		Ipsilateral Stimulation		TEOAEs		DPOAEs	
	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear	Right Ear	Left Ear
1	95	90	90	90	Present	Present	DNT	DNT
2	100	95	90	95	Present	Present	DNT	DNT
3*	NR	95	90	100	Reduced	Reduced	Present	Present
4*	100	90	95	95	Present	Present	DNT	DNT
5*	95	100	95	95	Present	Present	DNT	DNT
6	95	95	95	90	Present	Present	DNT	DNT
7	90	N/A	N/A	95	Absent	Present	Reduced	Present
8	90	95	90	90	Present	Present	DNT	DNT
9	95	95	100`	100	Present	Present	DNT	DNT
10*	N/A	N/A	95	N/A	Present	Present	DNT	DNT

Note. ARTs indicate Acoustic Reflex Thresholds, OAEs indicates otoacoustic emissions, TEOAEs indicates transient evoked otoacoustic emissions, DPOAEs indicates distortion product emissions, NR indicates no response at highest intensity (110 dB HL), N/A indicates equipment malfunction unable to obtain ART, Present indicates present and robust emission, Reduced indicates reduced amplitude emission, Absent indicates absent emission, DNT indicates did not test, and *indicates participants not included in aggregate data analysis.

Two of the remaining six participants met the diagnostic criteria for a diagnosis of APD using the TU-APD battery. One of these participants received a diagnosis of APD (Participant 2). But the other participant (Participant 1) that met the criteria for a diagnosis of APD based on her test results, did not receive a formal diagnosis due to two confounding factors: bilingualism and language disorder. However, for the purpose of aggregate data analysis, Participant 1 was classified as having APD based on the diagnostic criteria used in the study.

The NT-APD tests supported the TU-APD findings of APD for the same two participants (Participant 1 and 2) by falling into the "significant weakness" category (2 SDs from mean) on two tests (Table 7). The sensitivity and specificity for the NT-APD were 100% when comparing these results to the TU-APD for this small sample. Displayed in Table 8, Table 9, and Table 10, are the proportion of abnormal or normal based on testing method for temporal processing tests, monaural low redundancy tests, and dichotic listening tests, respectively.

To examine the proportion of abnormal scores obtained through the traditional testing and new technology, McNemar's test were performed with six participants. McNemar's tests indicated no significant difference between the proportions of participants classified by the NT-APD when compared to score obtained on the TU-APD as seen in Table 11.

Table 7

Breakdown of Diagnosis by Testing Method

		TU-APD		
		Normal	Abnormal	Total
NT-APD	Normal	4	0	4
	Abnormal	0	2	2
	Total	4	2	6

Table 8

Contingency Tables of Temporal Processing Tests

		TU-APD: GIN		
		Normal	Abnormal	Total
NT-APD : Speed Whistles	Normal	4	1	5
	Abnormal	1	0	1
	Total	5	1	6

		TU-APD: FPT		
		Normal	Abnormal	Total
NT-APD: Whistle Code Breaking	Normal	5	0	5
	Abnormal	0	1	1
	Total	5	1	6

Table 9

Contingency Tables of Monaural Low Redundancy Tests

		TU-APD: CID W-22 in Noise		
		Normal	Abnormal	Total
NT-APD: Target Practice	Normal	4	2	6
	Abnormal	0	0	0
	Total	4	2	6

		TU-APD: CRW		
		Normal	Abnormal	Total
NT-APD: Speed Codes	Normal	5	0	5
	Abnormal	1	0	1
	Total	6	0	6

Table 10

Contingency Tables of Dichotic Listening Tests

		TU-APD: SSW		
		Normal	Abnormal	Total
NT-APD: Double Codes	Normal	4	1	5
	Abnormal	0	1	1
	Total	4	1	6

Right Ear		TU-APD: DDT		
		Normal	Abnormal	Total
NT-APD: Double Animal Codes	Normal	5	0	5
	Abnormal	1	0	1
	Total	6	0	6

Left Ear		TU-APD: DDT		
		Normal	Abnormal	Total
NT-APD: Double Animal Codes	Normal	6	0	6
	Abnormal	0	0	0
	Total	6	0	6

Table 11

McNemar's Test for Comparison of Testing Method

TU-APD	NT-APD	*p*
Diagnosis	Diagnosis	1.00
CID W-22 in Noise	Target Practice	0.50
CRW	Speed Codes	1.00
FPT	Whistle Code Breaking	1.00
GIN	Speed Whistles	1.00
SSW	Double Codes	1.00
DDT	Double Animal Codes	1.00

CHAPTER 5

Discussion

Results of this pilot study indicate that the Feather Squadron app needs further testing before it can be recommended for APD testing. Statistical significance testing was limited due to the heterogeneous population and small sample size, which affected the ability to cleanly analyze the proportion of NT-APD to TU-APD diagnostic results. Some of the data were incomplete, based on the co-morbid disorders; therefore, using statistical significance testing for this pilot data would be premature at this point. A case by case discussion of some of the participants will occur in this section.

Case Studies

Case #1. Participant 10 was excluded in aggregate data analysis based on multiple diagnoses indicated on the case history report. His diagnoses included ASD, speech and language disorder, and ADHD. This participant was recruited from the APD waitlist at TU HBC.

Basic audiologic results were normal and the cognitive screener scaled score was within normal limits. This participant currently has an IEP and receives SLP therapy bi-weekly for 30 minutes each session. The parent reported that he is mainstreamed in the regular curriculum classroom but has a one-on-one aide to help keep him on task. An attempt was made to assess his auditory processing abilities using the TU-APD battery but, repetitive behaviors such as rocking and random utterances of numbers and words affected testing. Additionally, the participant did not tolerate either the inserts therefore, headphones were trialed too. Additionally, he required constant reinstruction and multiple test breaks were required during the TU-APD testing. Testing was difficult to facilitate.

Despite all of the challenges with the administration of the TU-APD, three of the TU-APD tests (DDT, FPT, CRW test) were reliably assessed. Even though test administration was difficult, auditory processing abilities were found to be age-appropriate.

The participant's behavior during the computer app were a stark contrast to those seen during the traditional testing. When the computerized testing was performed, the participant was calm and quiet. The participant did not move from the chair nor speak repetitive phrases, whereas, during traditional testing, it was extremely difficult to keep the participant seated and quiet. Based on the scores obtained on the NT-APD, he failed only one subtest therefore, did not fulfill diagnostic criteria for APD. Of interesting note, the NT-APD testing took about 40 minutes to complete; in contrast, the three tests from the TU-APD battery took 1-hour and 45 minutes to administer due to all of the modifications required. If the NT-APD is externally validated then this case may provide support for the use of the NT-APD as a diagnostic tool for children with similar profiles.

Case #2. Participant 4 was excluded from aggregate data analysis due to a diagnosis of a mixed receptive/expressive language disorder. The participant was evaluated for APD three months prior to the research study, at an outside facility. This participant was referred to the TU HBC for a second opinion. The participant was seen as a part of this research study for his second opinion. He is attending a special education program for children with language disorders therefore, his language was screened prior to proceeding with APD testing to see if he met the minimum language requirements. Participant 4 did not meet the criteria of the CELF-4 screening test. He passed the nonverbal intelligence screening. The participant performed the NT-APD testing as part of this research study. Due to the known language disorder and failed CELF-4 screening test, the TU-APD was not performed but, the test results from the previous APD evaluation were used for comparison with the scores obtained on the computerized testing.

When looking at the TU-APD scores from the outside center, the results on temporal processing tests (Random Gap Detection Test, FPT, and Duration Pattern Test) were noted to be interpreted with caution due to patient factors (difficulty tolerating the insert earphones and difficulty comprehending the instructions for the tasks). The participant's scores for the CRW test, DDT, Competing Words-Directed Ear, and Competing Sentences were below age appropriate limits; however, it is important to acknowledge that most of these tests were language-loaded, therefore the results should not be considered accurate towards a diagnosis of APD. The participant only failed one of the NT-APD tests (Target Practice, the speech in noise equivalent) therefore, he did not meet the criteria for diagnosis of APD on the NT-APD. In conclusion, results of the TU-APD battery performed at the outside facility was consistent with an APD diagnosis, whereas the results of the NT-APD battery indicated age-appropriate auditory processing abilities. It is possible, based on the low-language loaded nature of the app, the NT-APD may provide a more valid indicator of auditory processing than the traditional test battery but, this should be explored further.

Case #3. This participant (Participant 1) was recruited from the auditory processing evaluation waitlist at the TU HBC. Participant 1 met the diagnostic criteria for APD but, did not receive a diagnosis of APD due to two confounding factors; she has an SLI and is bilingual. She receives 30 minutes of speech services weekly, specialized reading group, and instructional support provided through an IEP. The participant was bilingual with English as the dominant language, as she attended school which was taught in her primary language for part of the day. Parental report included anxiety and frustration in the school setting despite no formal diagnoses. This participant was tested over two, 3-hour sessions due to patient fatigue.

During the first test session the participant was shy and quiet. The tester had to rephrase directions to get responses. Assistance from experienced researchers was required to elicit participation. Conversely, at the second session the participant was outgoing and the testing proceeded without difficulty. The participant obtained abnormal scores on the SSW test and one ear of the speech in noise test. The participant's mother wanted to observe the app portion of testing and sat within the testing suite during the app portion. The participant appeared to be the most relaxed during the app portion. For NT-APD, Participant 1 obtained abnormal scores on language loaded tests which is consistent with the SLI diagnosis. In summary, both the NT-APD and TU-APD batteries indicated abnormal auditory processing abilities. Similarly, to Case #2, if this app is validated through future research, it may be a better a better way to assess children with language-based disorders since the NT-APD does not required verbal responding. Similarly, to Case #1, testing with the NT-APD may more engaging than TU-APD. The TU-APD took about 3-hours whereas, the NT-APD took about 40 minutes to complete. Like Case #1 the NT-APD was more time-efficient that traditional testing.

Case #4 & #5. Cases #4 and #5 are two participants (Participant 5 and Participant 3, respectively) who were excluded from aggregate data analysis due to abnormal pure tone thresholds. The normative data used for both the TU-APD (McDermott et al., 2016) and the NT-APD were obtained from people with normal hearing. Both participants' pure tone thresholds required modification to routine test procedures to obtain reliable responses. However, they were able to complete the APD testing and were found to have normal abilities on both the NT-APD and the TU-APD. Due to the variability on their diagnostic hearing assessment, they were both referred for additional testing.

Case #4. Case #4 (Participant 5) is was referred to TU HBC for an APD evaluation, after receiving conflicting audiologic results. Participant 5 brought past audiologic reports that varied from normal hearing to moderate sensorineural hearing loss. History of outer and middle ear infections were reported. The participant had vision issues that called for bifocals. Participant 5 did not have a formalized IEP but did have accommodations such as preferential seating, repeated directions, peer help, and extended time. She had present TEOAES, type A tympanograms and ARTs below 100 dB except for an elevated threshold in the left ear at 1000 Hz for contralateral stimulation. Audiologic results indicated a mild to moderate hearing loss with good pure tone average (PTA)-SRT agreement bilaterally. This participant was excluded from data analysis because the TU-APD tests are normed on children with pure-tone thresholds of 25 dB HL or better (McDermott et al., 2016). Prior to participation, Participant 5 had an ABR which revealed normal latencies and thresholds in response to click stimuli and thresholds of 50 dB nHL in the left ear and 20 dB nHL in the right ear in response to a 500 Hz tone burst. Because ANSD was ruled out based on the ABR, APD testing was administered. TU-APD testing was administered at normal intensities, despite elevated pure-tone thresholds and SRTs. The participant confirmed testing stimuli to be at a comfortable volume and did not want the volume to be louder. TU-APD results indicated age-appropriate auditory processing abilities, with only the speech in noise test score for the left ear in the below 2 SD range. The NT-APD tests also indicated normal auditory processing abilities with only one abnormal score (Target Practice) on the app. She were referred for further audiologic and medical testing; the results of this testing were not available at the time this thesis was completed. However, Case #4 demonstrates that once Feather Squadron is externally validated, the app may be useful for differential diagnosis, where other diagnosis were suspected but not yet confirmed. Initially, there were concerns about app performance due to the indicated vision problems; however, the participant successful completed the NT-APD portion and achieved age-appropriate scores. Further research is need into test response mode of the app due to the physical capabilities needed to respond.

Case #5. Participant 3 was recruited from the APD evaluation waitlist at the TU HBC. Participant 3 reported an occasional partial hearing loss; however, did not indicate that on the case history form. He described listening complaints that mimicked APD (i.e., difficulty understanding the teacher in a noisy classroom). Participant 3 indicated receiving IEP-like accommodations, such as preferential seating, due to these difficulties. Jerger type A tympanograms, reduced amplitudes for TEOAEs, and present and robust DPOAEs were obtained. Pure-tone testing was performed twice due to poor PTA-SRT agreement bilaterally and questionable validity. Participant 3 was reinstructed and testing was repeated. Testing indicated essentially normal hearing with good PTA-SRT agreement. WRSs were 100% bilaterally at a presentation level of 50 dB HL. TU-APD testing was also administered at elevated intensities secondary to participant requests. TU-APD testing revealed age appropriate auditory processing abilities with only one abnormal score on the speech in noise test for the left ear. App testing was administered at normal intensity (50% volume) and no volume complaint was voiced. NT-APD testing also indicated normal auditory processing abilities with only one abnormal scores on the Target Practice (NT-APD equivalent to the speech in noise test). Participant 3 was referred for further testing. Similarly to Case #4, the Feather Squadron may be useful for differential diagnosis and to rule out APD. Further research is needed to assess the benefit of utilizing the app as a tool to rule out APD in cases of inconsistent hearing results; however, Feather Squadron acts as screening measure rather than diagnostic tool in this situation.

Case #6. Participant 9 was referred to the TU HBC after a failed APD screening at an outside facility. Previous audiologic reports included a recent audiologic evaluation and an ABR which were both normal. The participant's parent indicated the participant had IEP-like accommodations such as preferential seating due to listening difficulties. The participant obtained elevated ARTs (100 dB HL) bilaterally for ipsilateral stimulation. The participant was very compliant during testing. TU-APD testing revealed age-appropriate auditory processing abilities with one abnormal score for the GIN test in the left ear. All app test scores were within normal limits. This case presenting an interesting example of the difference between screening and diagnostic tests. Participant 9 has listening complaints, normal hearing, normal ABR results, and failed an APD screening measure. Based on this, one would expect the participant to score poorly on APD testing. The GIN test was the last to be administered in the test battery with the starting ear being the right ear and the abnormal score on the GIN test was slightly outside the normal range, which may potentially be attributed to fatigue. The APD screening tool utilized was the SCAN-C. Participant 9 received questionable scores on the filtered words and auditory figure-ground subtests, a disordered score on the competing words subtest, and a normal score on the competing sentence subtest. Both diagnostic tests indicated age-appropriate auditory processing abilities, yet the screening tool suggested disordered auditory processing skills. If the Feather Squadron is proven valid, this case may illustrate the clinical utility as a screener. The outside audiologist administered the SCAN due to a lack of expertise in the area of pediatric APD. This case indicates the future potential of allowing audiologists not well-versed in APD to administer auditory processing testing.

These case studies presented the highlights and challenges of assessing auditory processing abilities in a small group of participants with listening concerns and/or suspected APD. Furthermore, these cases exemplify the ease of administration of the NT-APD and how it compares to the TU-APD for special populations or difficult to test children.

Potential Advantages of NT-APD

It is important to note the favorable aspects of the app. As demonstrated by the case studies, Feather Squadron was quick and simple to administer and the participants appeared to be engaged during the testing with the app. When informally asked about preference of test methods, all of the participants indicated that they enjoyed and preferred the Feather Squadron app over the TU-APD testing. The examiner also reported that the app required less effort from the participant. Case #1 and #3 are examples of situations where it may be easier to assess APD using the NT-APD. Both participants were more challenging to test using the TU-APD as compared to the NT-APD assessment. It should also be noted that the TU-APD testing was difficult to facilitate and exhausting for the examiner when challenging participants presented. Subjectively, the participants appeared to be more engaged and motivated when being assessed with the NT-APD as compared to the TU-APD methods.

Another benefit of app is standardized test administration. Scoring and interpretation of responses is performed and calculated by the app which takes away the subjective variability of test administration and/or interpretation of results (Cacace & McFarland, 2013; DeBonis, 2015; Emanuel, 2002; McDermott et al. 2016; McFarland & Cacace, 1995; Moncrieff, 2015). Different normative data, audiometer set-up, presentation level, number of test items, and scoring method can vary greatly. McDermott and colleagues (2015) collected normative data for TU-APD tests and compared the data to past research to find that the norms differed based on test administration and population assessed. Therefore, the streamline nature of tablet-based test battery may be an improvement to APD testing; however further exploration is needed.

Comparison to the Literature

There is only one publication on the Acoustic Pioneer app (Barker & Purdy, 2015). The article's focus was on typically developing children; consequently, the current study was performed with participants suspected of APD to investigate the efficacy of the app. The results of the present study conflict with previous literature. The results of this pilot study do not find statistically significant differences for any of the seven comparisons between the TU-APD and NT-APD batteries, but the sample size was small indicating the need for a larger scale study. Presently, there is not enough support for the utilization of the Feather Squadron app in the clinical setting for diagnosis of APD. The article by Barker and Purdy (2015) found evidence to illustrate a correlation between TU-APD and NT-APD, suggesting good validity of the app. This finding needs to be externally validated at another site or several sites.

Another difference between studies is that Barker and Purdy (2015) paired NT-APD subtests with different TU-APD tests, then used by the present study. One specific different is that Barker and Purdy (2015) paired the DDT with Double Codes which may be a more appropriate pairing than the SSW test and Double Codes pairing used by this study. Future research should consider these pairings when designing a study.

The current study and the study by Barker and Purdy (2015) utilized the FPT in comparison to the Whistle Code Breaking game; however, the results of the Whistle Code Breaking game were used differently. For the current study, the score used for comparison was the tonal-pattern temporal processing result, whereas the previous study utilized the tonal-pattern memory result. The tonal-pattern temporal processing was utilized because it was the most similar to the FPT and tonal-pattern memory was resembled an auditory sequencing task. Both the tonal-pattern temporal processing score and the tonal-pattern memory score were both based on Whistle Code Breaking results but were calculated differently. This difference should be addressed in future studies.

The test versions of the traditional APD tests were administered differently. Testing for the current study was administered in accordance to past research, in a sound treated suite, by an audiology graduate student under the supervision of a licensed audiologist. While, the FPT was administered binaurally via an iPad and headphones by a volunteer (not formally trained in audiology) in a quiet room (Barker & Purdy, 2015).

The authors of the previously mentioned study did not indicate which version of the Acoustic Pioneer app was utilized and if regional normative data is utilized for each version (New Zealand, U.S.A., etc). Research by Kelly (2007) and McDermott and colleagues (2016) emphasized the importance of knowing the normative data parameters (i.e., numbers) which is not available for the Feather Squadron app. There are many differences from this study to the study by Barker and Purdy (2015).

Limitations and Future Direction

There were many limitations to this study. The small sample size of this pilot study (n =10) does not provide enough support to comment on the validity of the app, especially considering that four of the 10 participants were excluded from aggregate data analysis. Future studies should include significantly more participants with children previously diagnosed with APD due to the heterogeneity of the population (Barker &Purdy, 2015; Musiek, Bellis, & Chermak, 2005). This would allow for a better evaluation of the relationship between the two test methods and an assessment of the validity of the Feather Squadron app (Barker & Purdy, 2015).

Another area that could be expanded on is the age range of participants assessed. The six participants in this study ranged in age from age 8 to 12 years. Further research is needed with children age 7 to 17. While the app can assess children younger than age 7, the minimum criterion for TU-APD tests is seven years.

Due to the differences in tests utilized in the TU-APD for the comparison to the Feather Squadron subtests, future studies should examine the pairing of TU-APD tests and NT-APD tests (Barker & Purdy, 2015). For the current studies, the tests chosen for the TU-APD were based on test stimuli, Feather Squadron reports, and auditory processes assessed. However, Barker and Purdy (2015) evaluated validity of the Feather Squadron app with different TU-APD tests, illustrating the inconsistencies amongst auditory processes measured and TU-APD test resemblance.

There are several challenges to assessing for APD in the school-aged population (DeBonis, 2015). If validated the app could address several concerning issues about the APD assessment: standardization of administration and scoring, time, and consistent test battery (Chermak, Silva, Nye, Hasbrouck, & Musiek, 2007; DeBonis, 2015). While the NT-APD shows promise as a new tool for either screening or diagnosis, there is still a lot of research that must be conducted to identify if the assessment is valid for the heterogeneous population with APD. Although the Feather Squadron is intended to be a diagnostic tool, there may be clinical utility as a screening instrument (Barker & Purdy, 2015). Due to simple administration, other professionals could utilize this application as a screener for APD and based on this could refer to audiologists for TU-APD testing to assess for APD.

The linguistic load (including instructions) should be evaluated for the NT-APD. If found to be low-linguistically loaded it may further support the use of the NT-APD with people that have co-occurring disorders (e.g., Case #1, #2 and #3). APD has a high comorbidity with speech or language disorders (Bamiou et al., 2001; Chermak, 2002; Ferguson et al., 2011; Gomez & Condon, 1999; Loo et al., 2013). Four of the 10 participants reported diagnoses of speech or language disorders with concerns about listening. Case #3 is an example of how a documented language impairment can confound the results of APD testing; leading to questioning if performance was due to APD or language processing. It is important to note that speech and language impairments indicate a wide range of abilities (ASHA, 2005b). Further research is needed to evaluate the Feather Squadron app as a valid tool to measure auditory processing abilities when speech and/or language are a concern.

Conclusion

This pilot study evaluated a new app-based APD diagnostic test. The findings from this study found several positives (i.e., administration time, ease of scoring) and other areas to further evaluate. It is important to acknowledge that the first author of the only study published on the NT-APD test tool is a partial owner of the app and has financial interest in it (Barker & Purdy, 2015).

While it was not one the aims of this study, this research further supports the heterogeneity of this population of children referred for APD testing (Bamiou et al., 2001; Dawes & Bishop, 2009; Ferguson et al., 2011; Jerger & Musiek, 2000; Loo et al., 2013). This study also highlight the potential for NT-APD in assessing difficult to test children. This study illustrates the complexity of testing for APD and the diversity of the population referred for the assessment. Only one of the 10 participants (10%) was diagnosed with APD, which is consistent with the previous prevalence estimates of APD in a pediatric population (Nagao et al., 2016).

The case studies presented indicate how patient factors and comorbidity may play a role in APD assessment and/or diagnosis. Recently, literature regarding new tablet-based testing and/or treatment of disorders has emerged (Cacace & McFarland, 2013; Given et al., 2008; Loo et al., 2010; Sharma et al., 2012; Rouse & Krueger, 2004; Stevens et al., 2008; Yeung et al., 2013). This study does not substantiate the Feather Squadron app as a replacement for TU-APD testing; however, it can be stated that the Feather Squadron app has the potential be a useful tool.

Appendix A: Case History Form

1. Is your child a native speaker of English/is English your primary language? Y / N

2. Has your child had any surgeries to his/her head or neck? Y / N

If so, when and for what? ____________________________

3. Has your child ever been diagnosed with any neurologic or degenerative disorder? Y / N

If so, what? _____________________________________

4. Has your child ever been diagnosed with a hearing loss? Y / N

5. Does your child have a history of chronic ear infections? Y / N

If so, when was your child's last ear infection? __________________________

6. Has your child ever been diagnosed with an auditory processing disorder? Y / N

If so, when and where? _______________________________________

7. Do your child have any difficulty with communication? Y / N

8. Has your child ever been diagnosed or treated for ADHD (or ADD)? Y / N

If so, when? _______________________________________

If so please have your child take his/her medication on the day of participant.

9. Have your child been diagnosed with a learning and/or language disorder? Y / N

If so, what? _______________________________________

10. Do you suspect your child has a learning and/or language disorder? Y / N

Why? ____

11. Do your child receive any special services at school through an Individualized Education Plan (IEP) or 504 plan? Y / N

If so, what? _____________________________________

12. Is there anything else we should know about your child?

____

____

____

Appendix B: Institutional Review Board Approval

TOWSON UNIVERSITY

APPROVAL NUMBER: 16-A053

To: Katherine Maffetone
Van Bokklen Hall 103B
Towson MD 21252

From: Institutional Review Board for the Proctection of Human Subjects Devon Dobrosielski

Date: Tuesday, December 08, 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:

Auditory Processing Disorder: A Comparison of Traditional Testing Methods and New Technology

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: S. Nagle
File

TOWSON
UNIVERSITY

Date: Tuesday, December 08, 2015

NOTICE OF APPROVAL

TO: Katherine Maffetone **DEPT:** ASLD

PROJECT TITLE: *Auditory Processing Disorder: A Comparison of Traditional Testing Methods and New Technology*

SPONSORING AGENCY: None

APPROVAL NUMBER: 16-A053

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: 08-Dec-2015
This research will be reviewed every year from the date of first approval.

Amy Taylor for

Devon Dobrosielski
Towson University Institutional Review Board

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CURRICULUM VITAE

NAME: Katherine Maffetone, B.A.
PERMANENT ADDRESS: 2194 Spruce St
Wantagh, NY 11793
PROGRAM OF STUDY: Doctor of Audiology (Au.D.)

DEGREE AND DATE TO BE CONFERRED: Doctor of Audiology, May 2017

Collegiate Institutions Attended	Dates	Degree	Date of Degree
Loyola University Maryland Major: Speech Language Pathology and Audiology Minor: Special Education	2009-2013	Bachelor of Arts	May 2013
Towson University	2013-2017	Doctor of Audiology	May 2017

Professional positions held:
Alfred I. duPont Hospital for Children
Chesapeake Ear, Nose, & Throat
ENTAA Care
Kennedy Krieger Institute

Fourth year residency position: Weill Cornell Medical College