TOWSON UNIVERSITY
OFFICE OF GRADUATE STUDIES

THE EVALUATION OF AN APP-BASED THERAPY PROGRAM FOR AUDITORY PROCESSING DISORDER: A PILOT STUDY

by

Hanna Moses

A thesis

Presented to the faculty of

Towson University

in partial fulfillment

of the requirements for the degree

Doctor of Audiology

Department of Audiology, Speech Language Pathology and Deaf Studies

Towson University
Towson, Maryland 21252

May 2016

TOWSON UNIVERSITY
COLLEGE OF GRADUATE STUDIES AND RESEARCH

AUDIOLOGY DOCTORAL THESIS APPROVAL PAGE

This is to certify that the thesis prepared by Hanna T. Moses, B.S., Au.D. Candidate, entitled: The Evaluation of an App-Based Therapy Program for Auditory Processing Disorder: A Pilot Study has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree Doctor of Audiology (Au.D.)

Jennifer L. Smart, Ph.D.
Chairperson, Thesis Committee

5/2/2016
Date

Andrea S. Kelly, Ph.D.
Committee Member

5/2/16
Date

Stephanie Nagle, Ph.D.
Committee Member

5/2/16
Date

Janet DeLany, D.Ed.
Dean of Graduate Studies

5-16-16
Date

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my thesis advisor, Dr. Jennifer L. Smart, for her dedication, patience, and excellent guidance. I hope you know how much I appreciate all that you have done for me, and how much you have helped me through the thesis process, as well as throughout the program. You always have the upmost confidence in your students, and for that, I am forever grateful. I would also like to thank my thesis committee members, Dr. Stephanie Nagle and Dr. Andrea Kelly, for their expertise, assistance, and commitment to my thesis. I am truly honored to have worked with such a dedicated, encouraging, and intellectual group of individuals.

My family has also played a major role in supporting me throughout the entire graduate school journey. Thank you, mom, dad, and Cindy, for your unwavering support during college and graduate school, as well as your love and encouragement for the past 25 years. To my brother, Joe, you are a wonderful source of advice and a confidant, thank you for always knowing exactly what to say. Lastly, I would like to thank my friends, which includes those from home, as well as my cohort. I am so lucky to have had the opportunity to meet each and every single one of you along the way. Thank you all for being so supportive and keeping me laughing through good and bad times.

ABSTRACT

The Evaluation of an App-Based Therapy for Auditory Processing Disorder:

A Pilot Study

Hanna Moses

Individuals with auditory processing disorder (APD) have listening difficulties despite normal hearing thresholds (Chermak, 2002; Moore, 2006). This population presents heterogeneously. They can have deficits in one or more different areas of auditory processing, and commonly have co-occurring disorders (AAA, 2010; Chermak, 2002; Witton, 2010). This variability in presentation and symptoms can make it challenging to develop intervention strategies to treat this population. Throughout the years there have been computer-based programs that claim to treat APD (e.g., Earobics, and Fast ForWord), and more recently, an application (app)-based therapy has been developed. The purpose of this study was to evaluate the potential benefit of a new app-based therapy for children with APD.

Five children, aged 7 to 11 years with confirmed or suspected APD were recruited for this study. Prior to starting therapy, their language, nonverbal intelligence, and hearing levels were screened. They were also administered two clinically used tests of auditory processing (the Frequency Pattern Test and the Dichotic Double Digits Test) and an app-based diagnostic evaluation.

Each participant was seen twice a week for 6 weeks of therapy. All participants engaged in the two app therapies regardless of their auditory weakness (temporal and/or dichotic listening deficits). Each therapy session lasted approximately 30-45 minutes in duration. After completion of the 6 week therapy, each participant was re-administered the same tests of auditory processing and the app-based diagnostic evaluation again. Statistical analyses revealed there were no significant differences in test scores pre vs. post-therapy for either the tests of auditory processing or the app-based diagnostic evaluation for all participants. Improvements in test scores and therapy progress were variable among participants. The results from the pilot data indicated the benefit of the app was difficult to predict and results were conflicting at times (e.g., the app indicated a need for therapy, yet the participant completed therapy in one week). The findings from this study indicate the need for a larger scale study to more accurately determine the efficacy of this app-based therapy for the treatment of APD.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

Auditory processing is the brain's ability to understand and manipulate auditory information (ASHA, 2005). Auditory processing disorder (APD) refers to deficits in understanding spoken messages despite normal hearing sensitivity. Children with APD oftentimes report hearing loss-type complaints such as difficulty listening in background noise, the need for constant repetition, inattentiveness, difficulty following rapid or degraded speech, poor singing or musical abilities, inappropriate responses to questions, and academic difficulties (Bamiou, Musiek, & Luxon, 2001; Chermak, 2002; Dobrzanski-Palfrey & Duff, 2007; Friel-Patti, 1999; Chermak & Musiek, 1992). These symptoms are due to a deficit in one or more of the following processes: dichotic listening, temporal processing, localization and lateralization, and listening in degraded environments (AAA 2010, Bamiou et al., 2001; Chermak, 2002). APD can have negative impacts on a child's communication abilities, academic success, and social interactions. Therefore, early identification of APD is essential in implementing appropriate intervention strategies, which will ultimately enhance the individual's success in everyday life.

After an accurate diagnosis of APD is made, intervention can take several forms. Typically, a combination of management and treatment strategies are assigned (Chermak & Musiek, 2002). Management strategies are typically introduced by an audiologist or speech-language pathologist, and are aimed at working around the auditory deficit (Keith, 1999). Treatment is carried out in a structured, controlled environment, and is aimed at reorganizing the cortical pathways of the brain. Treatment is often times administered through the use of computer or application-based technology (Keith, 1999). Researchers have recently discovered that computer-based therapy programs have shown improvements in a variety of auditory processes (Baran, Shinn, & Musiek, 2006; Chermak, 2002; Gillam, et al., 2008). However, other researchers have shown these improvements may not result in long-term cortical changes (Chermak, 2002; Moore, 2011). Despite the conflicting literature, investigators agree more research is needed to determine long-term effects of computer and application-based treatment programs (Bamiou, Campbell, & Sirimanna, 2006; Chermak, 2002). Therefore, the purpose of this study is to determine the effectiveness of a new application-based therapy program, Acoustic Pioneer, on auditory processes in children.

Chapter 2

Literature Review

What is APD?

Definition. APD is, simply put, listening difficulties in the presence of normal hearing thresholds (Chermak, 2002; Moore, 2006). Individuals with APD have difficulty processing auditory information, especially when the acoustic signal is complex or degraded (Keith, 1999). For example, these individuals may have difficulty understanding speech in the presence of background noise, reverberation, and/or when the signal is rapid or degraded (Chermak, 2002; Keith, 1999).

Individuals with APD often experience a deficit in at least one of the auditory processes responsible for the following phenomena: sound localization and lateralization, auditory pattern recognition, auditory discrimination, processing degraded acoustic signals and competing stimuli, or temporal processing (which includes temporal resolution, temporal masking, temporal integration, and temporal ordering) (AAA, 2010; Bamiou et al., 2001; Chermak, 2002; Dobrzanski-Palfrey & Duff, 2007; Keith, 1999; Miller, 2011). In addition to these auditory deficits, APD can occur with speech, language, and/or learning difficulties due to overlapping regions of the brain responsible for these cognitive abilities (Witton, 2010).

APD vs. CAPD. Central auditory processing disorder (CAPD) or (C)APD are two terms used to refer to auditory processing disorder. The “C” is used to identify the potential involvement of the central auditory nervous system (CANS), which includes pathways from the cochlear nucleus in the brainstem up to the primary auditory cortex of the brain (Dobrzanski-Palfrey & Duff, 2007; Keith, 1999). Some researchers suggested the word “central” should not be used because it is too specific to the location of the deficit and is often used inaccurately (Debonis & Moncrieff, 2008). Emanuel, Smart, Bernhard, and McDermott (2013) examined the popularity of the terms CAPD, (C)APD, and APD among websites and peer-reviewed literature. They found the term APD was used most commonly used among researchers in the field, and suggested that this terminology be used to lessen confusion among patients and professionals (Emanuel et al., 2013). Therefore, the term APD will be used for the remainder of this paper.

Prevalence. APD is prevalent among children and older adults, and is estimated to be in about 3% of children and 20-30% of adults older than 60 years of age (Chermak, 2002; Dobrzanski-Palfrey & Duff, 2007). The relatively high prevalence of APD in these age groups has gained legal attention in the United States (Dobrzanski-Palfrey & Duff, 2007). APD qualifies as a learning disability under the Individuals with Disabilities Education Act (IDEA) and is considered a physical disorder according to the Americans with Disabilities Act (ADA), requiring specific treatment and management (Dobrzanski-Palfrey & Duff, 2007). Due to the impact APD has on communication, it is imperative that education and health care professionals recognize signs and symptoms in order to facilitate early diagnosis and intervention.

Signs and Symptoms

Presentation of APD. APD encompasses deficits specific to the auditory system. These deficits result in symptoms and behaviors commonly associated with APD. According to Bamiou et al. (2001), difficulty hearing in the presence of background noise is the most commonly reported symptom of APD. Other commonly reported symptoms include difficulty following oral instructions, need for constant repetition, difficulty understanding rapid speech, inattentiveness, difficulty understanding sarcasm or prosody changes, poor singing and musical abilities, slower information processing, a history of chronic otitis media, and difficulty paying attention (Bamiou et al., 2001; Chermak, 2002; Foli & Elsisy, 2009; Ryan & Logue-Kennedy, 2013). Individuals with APD often experience academic difficulties such as reading disorders, spelling problems, and poor handwriting (Keith, 1999). Academic delays are also commonly reported signs of APD because cognitive tasks require attentive listening and processing of complex auditory information, which are skills that are often deficient among these individuals (Chermak, 2002; Rosen, Cohen, & Vanniasegaram, 2010; Ryan & Logue-Kennedy, 2013; Keller, Tillery, & McFadden, 2006). In addition to academic delays, those with APD may display behavioral problems as a result of their frustrations with understanding auditory information (Keith, 2009). They may also be withdrawn and/or shy because they feel inferior to peers due to academic performance or difficulties listening in social situations (Foli & Elsisy, 2009; Keith, 1999).

APD symptoms are not typically recognized until the child reaches school age, where the listening demands and acoustic environments become more challenging (Bamiou et al., 2001). Because symptoms typically present in school, it is imperative that teachers are educated and aware of what APD is and the implications it can have on learning (Ryan & Logue-Kennedy, 2013). A study conducted by Ryan and Logue-Kennedy (2013) evaluated the awareness, knowledge, and education about signs and symptoms that primary school teachers received on APD. Of the 137 completed questionnaires, 89% of respondents indicated poor or very poor awareness of APD, and 99.3% reported never receiving formal APD training (Ryan & Logue-Kennedy, 2013).

Teachers and education professionals should have a basic understanding of APD because it can be associated with other disorders that have similar manifestations (Ryan & Logue-Kennedy, 2013; Witton, 2012).

Comorbidity. APD can occur in the presence of other disorders, making a differential diagnosis challenging. APD may occur with speech, language, attention, and learning disorders (Chermak, 2002; Chermak et al., 1991; Sharma, Purdy, & Kelly, 2009; Witton, 2010). Because other disorders can be comorbid with APD, educators and other professionals should be aware of these co-occurrences to ensure the child is receiving appropriate services (Witton, 2010). Sharma, Purdy, and Kelly (2009) conducted a study to determine the comorbidity between APD, language impairment, and reading disorders among children. They found 85% of participants (n=65) had APD in addition to either language impairment or a reading disorder. This research indicates that other disorders are more likely to occur with APD than not, and it is important to make sure that the child (or adult) is thoroughly assessed to ensure a co-occurring disorder is not missed (and therefore treatment delayed) (Sharma et al., 2009).

Several researchers have discovered attention deficits and APD commonly occur together (Breier, Fletcher, Foorman, Klaas, & Gray, 2003; Cherma, Somers, & Seikel, 1998; Riccio, Cohen, Garrison, & Smith, 2005). Riccio et al. (2005) examined the co-occurrence of APD with attention, memory, behavior and neuropsychological measures. Utilizing 36 children, researchers conducted various objective and subjective tests to diagnose APD, behavior, attention, and memory deficits. 72.2% of their participants were classified as having APD, and 44.4% of the participants had a diagnosis of APD and an attention deficit. Researchers noted that APD and attention deficits may be overlapping disorders, however, deficits in auditory processing may not be directly linked with attention deficits. Researchers state the disorders can co-occur, but a differential diagnosis can and should be made appropriately (Riccio, et al., 2005).

Differential diagnoses. There are several different disorders that may present similarly to APD. Two of these disorders often seen in the clinical population are ADHD and auditory neuropathy spectrum disorder (ANSD) (Chermak et al., 1998; Jerger & Musiek, 2000).

Attention deficit hyperactive disorder (ADHD). ADHD presents symptoms similarly to APD, however, distinctions exist between them, making a differential diagnosis possible. ADHD affects multiple sensory modalities while APD is specific to the auditory modality (Chermak, Hall, & Musiek, 1991). Chermak et al. (1998) conducted a study to determine behaviors and symptoms commonly seen in APD and ADHD. They created a survey for pediatricians and audiologists to rate behaviors exhibited among APD and ADHD patients. Although some behaviors overlapped (inattentiveness and distractibility), a greater number of behaviors were distinct to each category. For example, behaviors most commonly associated with ADHD were hyperactivity and poor self-control, while APD was associated with poor academics and specific auditory deficits such as difficulty following oral directions and hearing in background noise (Chermak et al., 1998). The researchers concluded that based on the results, definitive distinctions are able to be made between APD and ADHD based on observations and questionnaires (Chermak et al., 1998).

Although APD and ADHD are distinct, they can also co-occur. Despite the co-occurrence, a diagnosis of APD can still be made with appropriate precautions (Chermak et al., 1998; Keith & Engineer, 1991). Keith and Engineer (1991) conducted a study utilizing 20 children (ages 7-13) with diagnosed ADHD. They performed several auditory attention tasks on with the subjects on their medication (methylphenidate) and off medication. A control group comprised of children without ADHD or other diagnoses was used for comparison. They found that while the test group (children with ADHD) was on their medication, they were able to attend and complete the tasks as well as the control group. Keith and Engineer (1991) concluded that when testing for APD, children with ADHD can and should be tested as long as they have taken their appropriate medication.

Auditory neuropathy spectrum disorder (ANSD). APD and ANSD present overlapping auditory symptoms (Jerger & Musiek, 2000). ANSD is characterized as dysynchronous firing of the auditory nerve in the presence of normal outer hair cell functioning, synapse problems between the inner hair cells and the VIIIth nerve, and/or a neuropathic VIIIth nerve (Jerger & Musiek, 2000; Norrix & Velenovsky, 2014). Individuals with ANSD exhibit listening difficulties similar to individuals with APD. People with ANSD will have abnormal results from their peripheral hearing evaluation which include hearing loss ranging from normal hearing thresholds to a profound loss, abnormal acoustic reflex thresholds (ARTs), present otoacoustic emissions (OAEs), normal tympanometry, and poorer than expected word recognition scores based on hearing thresholds, especially in noise (Berlin, Hood, Morlet, Rose, & Brashears, 2003; Kumar & Jayaram, 2006). Despite similar symptomatology between ANSD and APD, differential diagnosis can be made if the clinician performs appropriate objective audiologic testing with the audiologic evaluation. This should minimally include OAEs, ARTs, pure-tone audiometry, tympanometry, speech and speech-in-noise testing (Berlin et al., 2003). ANSD should always be ruled out before proceeding with APD testing.

Etiologies. Etiologies common to the adult population include neurodegenerative diseases such as multiple sclerosis (AAA, 2010, Bamiou et al., 2001). Changes in neural function due to aging is also a common etiology of APD in adults. Several researchers examined older adults' (≥ 55 years) performance on central auditory tests, and found that neural mechanisms underlying speech discrimination break down with age (Bellis, Nicol, & Kraus, 2000; Golding, Carter, Mitchell, & Hood, 2004).

For children, common causes of APD are neurologic disorders or insults that damage the auditory system (Chermak, 2002). For example, childhood illnesses such as recurrent otitis media or hyperbilirubinemia cause auditory deprivation or damage to neural structures of the auditory system (AAA, 2010; Chermak, 2002; Moore, 2007). Children born premature often times have a low birth weight. This population can have APD, which will improve with development and maturation of the brain (Bamiou et al., 2001). Infants with prenatal exposure to cigarette smoke, alcohol, or postnatal anoxia are also at a greater risk for developing APD, as these factors can damage the brain's maturation (Bamiou et al., 2001). Severe head trauma can cause damage to pertinent parts of the brain, such as the corpus callosum, which is necessary for certain auditory processes (Bamiou et al., 2001; Dobrzanski-Palfrey & Duff, 2007; Moore, 2007). Although not well understood, APD is thought to have a genetic component as well (Bergemalm & Lyxell, 2005). Finally, in some individuals, it is unknown why they have APD (Musiek & Chermak, 2007).

Although the pathologies discussed can cause APD, they may also cause other unrelated physiologic disorders. It is important to differentiate between APD and any other associated manifestations of the disorder and to identify any co-occurring disorders. Determining appropriate candidacy for APD testing is essential for an accurate diagnosis and a proper treatment plan.

Who Can Be Assessed?

Determining candidacy for APD testing is essential for proper evaluation. There are several variables that can negatively influence the outcomes of testing, leading to inappropriate diagnoses, treatment, and management plans (AAA, 2010). These variables include age, cognitive abilities, language proficiency, speech intelligibility, and peripheral hearing status (Jerger & Musiek, 2000; Musiek, Gollegly, & Baran, 1984; Musiek, Gollegly, Kibbe, & Verkest-Lenz, 1991; Neijenhuis, Tschur, & Snik, 2004). Healthcare professionals, educators, and parents should be informed about candidacy requirements for testing for APD.

Peripheral hearing. Before proceeding with APD testing, a comprehensive evaluation of hearing abilities should be performed. Auditory processing abilities can be compromised in individuals with a peripheral hearing loss (Musiek et al., 1991; Neijenhuis et al., 2004). If a sensorineural hearing loss is found, then the hearing loss should be addressed (e.g., hearing aids, FM system, aural rehabilitation, etc.). Additionally, chronic conductive hearing losses and ANSD should be ruled out before proceeding with APD testing (Musiek et al., 1991).

Age. APD testing is not appropriate for children under the age of 7 due to the lack of CANS development in children (AAA, 2010; Musiek et al., 1984). Structures such as the corpus callosum, which are pertinent for interhemispheric transfer of auditory information, may not be completely developed until adolescence in some children (Musiek et al., 1984). Moreover, myelination, which covers the corpus callosum and is necessary for the transfer of information to other neural structures, is sometimes not complete until the age of 10 (Musiek et al., 1984). Due to the slow development of CANS structures, testing children under 7 years old would be inappropriate. It is recommended that a comprehensive audiological evaluation is performed along with behavioral checklists and, when available, screening measures administered to determine those who are at-risk for APD and are under the age of 7 (AAA, 2010). When a child is 7 or older, there are still other considerations that must be made when administering an APD test battery.

Cognitive ability. Audiologists must ensure the individual’s cognitive age is appropriate for APD testing. There are some individuals who may have intellectual disabilities or acquired brain injuries, and are unable to complete the APD test battery. Careful evaluation of the child’s cognitive abilities is necessary prior to testing or else results may be invalid (Bellis, 2003; Musiek & Chermak, 1997). In some instances, modifications to the tests and procedures may be necessary. Audiologists must understand the implications these changes may have on the validity of the test results (Bellis, 2003; Musiek & Chermak, 1997). A child must have a cognitive age of 7 or older and if there are concerns about intellectual abilities then a comprehensive educational psychological evaluation should be performed prior to the APD assessment.

Language proficiency and speech intelligibility. As noted previously, there are other disorders that commonly co-occur with APD such as speech and language difficulties (Sharma et al., 2009). Individuals with certain speech and language disorders may not be appropriate candidates for APD testing (Musiek & Chermak, 2007). Because many tasks in the APD test battery require verbal responses, it is imperative that individuals have appropriate expressive language skills (AAA, 2010; Musiek & Chermak, 2007). Those with severe articulation disorders may not be appropriate candidates for APD testing as it may interfere with the audiologist's ability to accurately score certain tasks (Jerger & Musiek, 2000). It is also important to ensure that the individual's vocabulary level is appropriate for testing (AAA, 2010). In addition to the expressive language demands, the directions for the tests are also demanding therefore the receptive language skills should also be in the normal range to accurately assess for APD. People with English as a second language (ESL) should have their language abilities evaluated before proceeding with the APD assessment to ensure that bilingualism isn't a factor in their difficulties.

The need for audiologic evaluation prior to testing. As previously stated, APD can be characterized as difficulty understanding and processing speech in the presence of normal peripheral hearing (Jerger & Musiek, 2000). The assessment for APD should begin with an audiologic evaluation to determine hearing status (Chermak, 2002). This evaluation should include pure-tone audiometry (air-conduction and bone-conduction), word recognition testing, otoacoustic emissions, and immittance measures (tympanometry and acoustic reflex thresholds) (Chermak, 2002). These tests are used to rule out any sensory or conductive pathologies that may be the cause of auditory processing difficulties (Chermak, 2002).

A recent study evaluated the prevalence of individuals reporting hearing difficulties in the presence of normal hearing thresholds, and the referral for such individuals (Hind et al., 2011). The researchers evaluated children (ages 0-16) and adult (ages 17-100) populations from two clinics in the United Kingdom. They found the prevalence of individuals with complaints of hearing loss but normal hearing to be 5.1% among children and 0.9% among adults. The prevalence among younger adults (ages 17-60) was 4%. Twenty-three percent of children were referred for APD testing following the audiologic evaluation, and almost all adults were discharged without a referral. The inadequacy for referrals is relatively high, especially among the adult (age 17 or older) sample (Hind et al., 2011). This indicates a greater percentage of individuals with possible APD who are not receiving the appropriate diagnosis or treatment.

It is important to provide an audiologic evaluation prior to APD testing to rule out individuals with a peripheral hearing loss whose auditory processing difficulties can be remedied by amplification. This audiologic evaluation will also be the first step in determining appropriate candidacy for APD testing, as conductive or sensory pathologies should be ruled out prior to testing (Chermak, 2002). Once appropriate candidacy has been determined, a comprehensive APD test battery can be performed for a proper diagnosis and if appropriate, recommendations for rehabilitation can be made (AAA, 2010).

Types of APD Tests.

Currently, there are no set criteria regarding test procedures and protocols for administering APD testing (AAA, 2010; Keith, 1999; Debonis & Moncrieff, 2008). When deciding which APD tests to administer, there are several important considerations. For example, the child's cognitive age and functioning, the content of the auditory stimulus (linguistically loaded or non-linguistically loaded content), should be considered prior to the evaluation (Keith, 1996). The tests chosen should have high validity and reliability, and should have complete normative data (Keith, 1996).

The use of non-linguistically loaded tests to distinguish APD from other language-based disorders is essential in appropriately diagnosing APD (AAA, 2010; Sharma et al., 2009). Sharma et al. (2009) found that almost half of their 68 participants diagnosed with APD had also had a reading and language disorder, and that 85% of the participants had at least two of those disorders comorbidly. Because such a large percentage of children with APD have associated language conditions such as dyslexia and specific language impairments, it is important that clinicians use non-linguistically loaded tests to eliminate confounding language disorders when making an APD diagnosis (Sharma et al., 2009; Miller, 2011; Moore, 2006). Researchers suggest that most individuals with speech-language impairments perform better on APD tests when tones and broad-band noises are utilized instead of speech stimuli (Miller, 2011; Moore, 2006). It is suggested that if a diagnosis of APD has been made using non-linguistically loaded materials, subsequent testing to support the diagnosis should include language-based test materials only when the status of a child's language abilities is known (Moore, 2006).

Despite a number of important topics to consider prior to selecting APD tests, there is no "gold-standard" in terms of which tests to include in a diagnostic battery (Debonis & Moncrieff, 2008). Some researchers suggest that because there are a number of accompanying disorders, as well as different ways APD presents itself, a diagnosis should made by a multidisciplinary team including audiologists and other professionals

(Foli & Elsisy, 2010; Moore, 2006). It has also been suggested that the battery contain valid, computer-based tests to eliminate listener bias and ensure an accurate diagnosis (Moore, 2006).

Although there is a lack of a uniform APD test battery, many researchers and clinicians agree there should be minimally one test from three to four of the following categories: temporal processing, dichotic listening, listening in degraded environments, and tests of localization and lateralization (AAA, 2010; Chermak, 2002). Musiek, Chermak, Weihing, Zapulla, and Nagle (2011) stated the number of tests used for an APD diagnosis does not necessarily increase the effectiveness of the battery. Instead, a minimum number of tests with high sensitivity and specificity assessing multiple auditory processes should be used (Musiek et al., 2011). A survey conducted by Emanuel, Ficca, and Korczak (2011) revealed the most common areas assessed in an APD battery by clinicians were dichotic listening, monaural low-redundancy speech, and temporal processing tests.

Dichotic listening tests. Dichotic listening tasks involve the presentation of different auditory stimuli to different ears simultaneously (Hällgren, Johansson, Larsby, & Arlinger, 1998). The perception of auditory stimuli uses both ipsilateral and contralateral pathways through the brain. However, with dichotic listening tasks, contralateral pathways are primarily used (Kimura, 1961). Individuals with APD can have difficulty processing competing auditory signals, especially speech stimuli, which is processed in the left hemisphere of the brain (Keith, 1999). Because dichotic listening tasks involve contralateral pathways through the brain, and speech is processed in the left hemisphere, a “right-ear advantage” phenomenon is sometimes present (Berlin, Lowe-

Bell, Cullen, & Thompson, 1972). This means the right ear's dichotic listening scores are better than the left because stimuli presented to the right ear crosses directly to the left hemisphere via the corpus callosum, whereas stimuli presented to the left ear crosses to the right hemisphere, and then back over to the left hemisphere for speech processing (Moncrieff, 2011). Children younger than 10 years of age often experience the right ear advantage because of a lack of CANS development, specifically the corpus callosum (Musiek, 1983).

Dichotic listening tasks involve either binaural separation or binaural integration. Binaural integration refers to the ability to recognize and combine auditory stimuli that is presented to both ears simultaneously (Musiek & Chermak, 2007). Binaural separation refers to the ability to distinguish auditory stimuli presented to both ears simultaneously (Musiek & Chermak, 2007). The tests used in dichotic listening tasks utilize either binaural separation, integration, or a combination of both (Musiek & Chermak, 2007). There are a variety of tests that are utilized to assess these dichotic tasks. The most common stimuli used are digits, words, and sentences (Musiek, 1983).

Digits. Tests utilizing digit stimuli include the Dichotic Digits and Dichotic Double Digits Test. Both the Dichotic Digits and the Dichotic Double Digits tests consist of either one or two digits presented to each ear simultaneously. In one version of the Dichotic Double Digits Test, the patient repeats all four digits. Forty digits (20 sets) are administered to each ear (Musiek, 1983). The number of correctly identified test stimuli is recorded for each ear. The number of correctly identified digits for each ear are then divided by 40 (the number of test stimuli per ear) to determine the percent correct per ear. These values are then compared to normative data to determine pass/fail criteria.

Words. The Staggered Spondaic Words (SSW) test is utilized by clinicians to assess APD in children, and is sensitive to temporal or parietal lobe lesions (Musiek, 1983). The SSW consists of two bisyllabic words presented to the individual. The first word is presented to one ear and the second is presented to the other ear. The first syllable of the first word is presented monaurally (noncompeting scenario). The second syllable of the first word is presented simultaneously with the first syllable of the second word to the other ear (competing scenario). The second syllable of the second word is presented monaurally (noncompeting scenario). The individual is instructed to repeat all of the words heard (Musiek, 1983). Despite the complex scoring, 62% of clinicians reported always using the SSW in their APD test battery (Emanuel, Ficca, & Korczak, 2011). There are other tests assessing dichotic listening abilities using words that are not listed due to their popularity.

Sentences. The competing sentences test (CST) is a test that includes 25 sentence pairs administered both ears at the same time (ref.). The participant is told to repeat the “target sentence” in either the right or left ears. The target sentence is administered at 35 dB HL, and the competing sentence in the opposite ear is administered at 50 dB HL. The participant then repeats back the target sentence. This is a test of binaural separation (reference). 59% of clinicians reported utilizing the CST in their clinical practice (Emanuel, Ficca, & Korczak, 2011).

Sensitivity and specificity of dichotic listening tasks. Several researchers have determined that the Dichotic Digits Test has a high sensitivity and specificity compared to other tests in the APD test battery (Hurley & Musiek, 1997; Musiek et al., 1991; Musiek et al., 2011). Researchers Musiek et al. (2011) studied the effectiveness, sensitivity, and specificity of several APD tests on individuals with varying CANS dysfunctions. The researchers found the Dichotic Digits Test yielded high specificity and sensitivity, even when the strictest passing criterion was applied for the participants (Musiek et al., 2011).

Temporal processing. Temporal processing tasks are utilized to test an individual's perception of auditory processing within a specific time domain (Musiek et al., 2005). Temporal processing is one of the most important aspects of auditory perception because all other features of auditory processing are impacted by the time domain (Musiek & Chermak, 2007). Individuals with APD, specifically cortical lesions or interhemispheric transfer dysfunctions, can have difficulties with temporal aspects of auditory signals, specifically temporal resolution, masking, integration, and sequencing (Bellis, 2003)**.** Temporal resolution and sequencing tests are most commonly used to assess temporal processing abilities (Baran, Shinn, & Musiek, 2006; Emanuel et al., 2011; Musiek et al., 2005).

Temporal resolution tests. The Gaps-in-Noise (GIN) and Random Gap Detection Test (RGDT) are both used to asses temporal resolution abilities. Temporal resolution is the ability of the auditory system to attend to rapid changes in the acoustic stimulus over time (Plack & Viemeister, 1993). The GIN test was developed to assess temporal resolution abilities in different types of clinical populations, as it does not require a verbal response and it can be used in adult and pediatric populations (Dias, Jutras, Acrani, & Pereira, 2012; Musiek et al., 2005). The GIN test has broadband noise segments that last 6 seconds. Each 6 second noise segment has 0 to 3 segments of silence (gaps) during each noise segment. The gaps vary in duration (2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 msec).

The patient is instructed to indicate when they perceive a gap in the noise. The threshold is defined as smallest gap duration (in msec) that the patient perceives 4 out of 6 times correctly (Baran et al., 2006). The RGDT is similar to the GIN test but is a more commonly used temporal resolution test (Emanuel et al., 2011). The RGDT presents auditory stimuli at different frequencies with randomized gaps in the stimuli of different durations (in msec). The patient’s task is to identify if one or two sounds were heard (Dias et a., 2012). Many researchers have recommended the use of GIN or RGDT because they have high test-retest reliability, do not require a verbal response, can be used in a variety of age populations, and have a reasonable administration and scoring time (Dias et al., 2012; Musiek et al., 2005).

Temporal sequencing tests. There are a variety of acoustic stimuli that can be used to evaluate temporal sequencing abilities (AAA, 2010). No matter the stimuli, temporal patterning and sequencing requires both right and left cerebral hemispheres (Musiek, 1994). The left hemisphere is needed for linguistically labeling auditory stimuli, while the right hemisphere is required for recognizing the acoustic contours of speech (Musiek, 1994).

One test utilized for temporal sequencing is the Duration Pattern Test (DPT). The DPT consists of three tones, each 1000 Hz. They are presented in a combination of either short or long durations. The short tones are 250 ms in duration and the long tones are 500 ms in duration (Musiek & Chermak, 2007). The patient is instructed to repeat the combination of tones heard (ex: long, short, short). The correct number of responses is divided by the total administered to find the percent-correct score per ear.

Even more commonly utilized than the DPT is the Frequency Pattern Test (FPT). According to Emanuel et al. (2011), 45.1% of practicing clinicians use the FPT in their APD test battery. The FPT is made up of three different tones. These tones are presented in a different combination of high frequency tones (1122 Hz) and low frequency tones (880 Hz) (Musiek & Chermak, 2007). The patient is asked to identify a three tone combination (ex. High, Low, High). The number of correctly identified test items for each ear are totaled. This number is then divided by the number of test items to determine a percent-correct score.

Researchers have determined that the FPT has a high sensitivity and specificity in determining cerebral lesions (Musiek et al., 2011; Musiek & Pinheiro, 1983). A study conducted by Musiek and Pinheiro (1987) performed the FPT on individuals with three different pathologies: brainstem, cortical, and cochlear lesions. They found the FPT was the most sensitive (83%) and specific (88.2%) to brainstem lesions. Similarly, researchers Musiek et al. (2011) determined sensitivity and specificity for numerous tests commonly utilized in an APD battery. They discovered that out of all of the tests commonly utilized, the FPT had the greatest sensitivity and specificity, which was 90% for both.

Monaural Low Redundancy. Monaural low-redundancy tests are administered one ear at a time, and the speech stimulus is distorted (Musiek & Chermak, 2007). Typically, the stimuli’s frequency, temporal, or intensity properties have been altered. Monaural low-redundancy tests examine the interaction between both extrinsic and intrinsic redundancy of the auditory system. Extrinsic redundancy occurs due to the acoustic features (frequency, intensity, and timing) and linguistic cues (phonemic cues, morphological cues, semantic cues, etc.) found in speech (Musiek & Chermak, 2007).

Intrinsic redundancy occurs within the physiological structures of the brain, which transmit information through the central auditory nervous system (CANS). This process is necessary for speech understanding. Individuals with APD can have a dysfunction (such as a lesion) in the level of the CANS, which means there is poorer intrinsic redundancy. Because of this, there is a potential for a breakdown in speech understanding when the speech is distorted (poor extrinsic redundancy). It is for this reason that monaural low-redundancy tasks are commonly utilized in a behavioral test battery for APD (Musiek & Chermak, 2007). Tests used to assess monaural low-redundancy abilities include time compressed speech (with and without reverberation), low and high-pass filtered speech, and speech-in-noise tests (AAA, 2010).

***Time compressed speech with and without reverberation*.** The Time Compressed Speech Plus Reverberation test requires the patient to repeat words that are 45% or 65% time-compressed. This test can be done with or without 0.3 seconds of reverberation (persistence of the acoustic stimulus in an enclosed area after the sound has stopped) (Musiek & Chermak, 2007; Wilson, Preece, Salamon, Sperry, & Bornstein, 1994). The number of correctly identified test items for each ear is determined, and then divided by the total number of test items to determine a percent-correct score. Approximately 55.8% of clinicians utilize the Time-Compressed Speech test, compared to only 8.4% utilizing Time-Compressed Speech with Reverberation in their APD test battery (Emanuel et al., 2011). This could be due to the fact that researchers have found little significance in performance between Time-Compressed Speech scores versus Time-Compressed Speech scores with reverberation at varying intensity levels (Wilson et al., 1994).

Low and high-pass filtered speech**.** Low-Pass/High-Pass Filtered tests are administered similarly to the Time Compressed Speech test. In one version of this test, the patient is asked to repeat NU-6 words that are either low-pass filtered above 1500 Hz or high-pass filtered below 2100 Hz (Bornstein, Wilson, & Cambron, 1994). The number of correctly identified items for each ear are recorded, and divided by the total number of items to determine the percent-correct score. Researchers compared scores from both Low and High-Pass Filtered Speech tests (Bornstein et al., 1994). They found little differences in scores between the two tests at a variety of presentation levels, therefore either test can be utilized in an APD test battery to test monaural low-redundancy skills (Bornstein et al., 1994).

Speech in noise testing**.** Obtaining word recognition scores in the presence of competing noise (i.e. white noise or filtered speech-spectrum noise) has been utilized to identify dysfunctions of the auditory system, such as brainstem lesions (Olsen, Noffsinger, & Kurdziel, 1975). Typically, monosyllabic words can be played in the presence of competing noise. The patient is instructed to repeat the word presented. The number of correctly identified words are totaled, and divided by the total number of test items to determine a percent-correct score. Several researchers have determined that identifying monosyllabic words in the presence of competing noise has been sensitive to identifying lesions from the auditory nerve up to the temporal lobe (Sinah, 1959; Dayal, Tarantino, & Swisher, 1966).

Overall, sensitivity and specificity for tests of monaural low redundancy are poorer compared to other tests in an APD battery. For example, researchers Karlsson and Rosenhall (1995) evaluated sensitivity of filtered speech tests on individuals with various

CANS lesions. They discovered only 62-64% sensitivity to brainstem lesions, and only 65-67% sensitivity to temporal lobe lesions. Similarly, Musiek et al. (2011) determined the sensitivity of the Filtered Speech Test (50%) to be considerably lower compared to other tests in a standard APD battery (i.e. competing sentences, frequency pattern, dichotic digits).

Localization and lateralization. The term “localization” refers to the ability to identify the direction of the sound outside in the environment (Plenge, 1974). The term “lateralization” refers to the ability to identify the location of a sound inside one’s head (Plenge, 1974). Individuals who have difficulty localizing and lateralizing sound often appear hearing impaired (Moossavi, Mehrkian, Lofti, Faghihzadeh, & Sajedi, 2014). Difficulties with these tasks typically impacts communication abilities with others (Moossavi et al., 2014).

Tests that assess localization and lateralization abilities are limited (AAA, 2010). However, several researchers developed the Listening in Spatialized Noise-Sentences test (LiSN-S) to evaluate these processes in individuals with APD (Cameron & Dillon, 2007; Cameron et al., 2009). The LiSN-S test creates a 3-D listening environment utilizing headphones. An acoustic stimulus is then presented to the listener from three different directions (Cameron & Dillon, 2007). The listener is asked to repeat target sentences in the presence of competing messages (Cameron et al., 2009). This test can be utilized to assess the ability to differentiate auditory signals arriving simultaneously (Cameron et al., 2009). Researchers Cameron and Dillon (2007) conducted a study to evaluate how well the LiSN-S assessed children’s ability to understand speech in background noise. The researchers suggest the LiSN-S test is an effective measure to evaluate auditory processing abilities in both adults and in children as young as 5 years old (Cameron & Dillon, 2007).

Intervention

Once an individual is diagnosed with APD, the clinician must decide how to intervene to remediate their auditory deficits. These intervention strategies must be introduced as early as possible to ensure permanent changes in the brain's processing abilities. The frequency, duration, and type of intervention strategy are highly dependent upon the clinician's preferences and the individual's needs and current abilities.

Neural plasticity and auditory training. Auditory training is the act of improving listening performance and processing auditory stimuli through practice and "training" exercises (Moore, 2007). The basis of auditory training is through the use of the brain's ability to grow, also referred to as "neural plasticity" (Moore, 2007). The brain has the ability to alter its synaptic growth and abilities through stimulation, deprivation, and learning, especially when the brain is still maturing (Bamiou et al., 2006; Moore, 2007). There are three types of neural plasticity: developmental, compensatory, and learning-related. When performing auditory training techniques, the brain is utilizing all three types of neural plasticity (Bamiou et al., 2006). Because of the human brain's ability to develop, compensate, and learn quickly, especially in a maturing brain, it is imperative that auditory training be incorporated soon after the diagnosis of APD.

Plasticity of the brain occurs over time, and continues through adulthood (Dahmen & King, 2007). Prenatally, cortical structures of the brain, specifically the primary auditory cortex, are underdeveloped and broadly tuned to acoustic stimuli (Zhang, Bao, & Merzenich, 2001). Zhang et al. (2001) utilized microelectrodes to compare changes and activity in the primary auditory cortex due to various tone-evoked stimuli in rat pups and adult rats. They discovered cortical responses to tones occur within the first two weeks post-birth. These responses activate a small range of neurons, as well as a less frequency-specific response compared to adults. More adult-like responses to various tones are present within the first 4 weeks of life. These developmental findings discovered in rats are similar to human cortical responses (Zhang et al., 2001). Neuronal responses to different tones give rise to speech understanding in later development (Dahmen & King, 2007).

As humans age, maturational changes continue to develop by forming new synapses in the brain, and eliminating older ones (Dahmen & King, 2007; Musiek, Shinn, & Hare, 2002). This process continues with aging, but is more rapid in infantile brains. The development and elimination of neural synapses then slows down into adulthood (Grutzendler, Kasthuri, & Gan, 2002). This stability in the brain during adulthood is critical for long-term memory and storage of sensory information, thus creating a more reliable and efficient auditory system (Dahmen & King, 2007; Grutzendler et al., 2002). Several researchers have determined, however, that new or practiced sensory experiences can give rise to cortical reorganization of the brain (Bao, Chang, Woods, & Merzenich, 2004; Polley, Steinberg, & Merzenich, 2006). However, this is best achieved during a “critical period,” or when the brain has not yet reached adulthood (Dahmen & King, 2007).

Cortical reorganization of the brain and new neural synapses due to auditory training can occur (Polley et al., 2006). For example, Polley et al. (2006) presented tones of different intensities and frequencies novel to adult rats. Researchers then trained the rats to recognize the various target tones by conditioning them to various food sources. Post-training, the adult rats had greater neural synapses in the primary auditory cortex for the frequencies targeted, as well as for frequencies surrounding the target. These cortical changes were due to learning-induced frequency training (Polley et al., 2006). Similarly, learning-induced cortical reorganization was observed for temporal training abilities as well (Bao et al., 2004). Bao et al. (2004) trained adult rats in a maze to determine the location of the food source by altering the repetition rate of pulsed noises. Essentially, the repetition rate increased as the rat moved closer to the food source. The researchers discovered greater neural synapses in the primary auditory cortex, and the neurons had greater phase-locking abilities post-treatment. These same temporal abilities allowed rats to recognize tone-pips in a shorter amount of time, indicating these learned-abilities can be transferred to similar auditory stimuli (Bao et al., 2004). These researchers have demonstrated that cortical reorganization of the brain is possible following auditory training, showing that the brain has a great deal of neural plasticity. Several researchers have shown neural plasticity is greatest at a younger age, and that there is a “critical period” for developing these skills (Geers, 2002; Kral & Sharma, 2012).

Musiek et al. (2002) stated that neural plasticity involves cortical reorganization of the brain, as well as developing new synaptic connections. Furthermore, Gold and Knudsen (2000) examined the effects of interaural timing differences of owls that were exposed to auditory deprivation utilizing acoustic filters. Owls that had unilateral auditory deprivation had greater cortical changes in the inferior colliculus and behavioral changes compared to the owls that had normal auditory exposure. This demonstrates plastic changes of the brain under deprivation conditions (Gold & Knudsen, 2000).

Similarly in humans, reorganization of the brain can result when there has been deprivation or damage to the auditory system (Musiek et al., 2002). For example, cochlear implant patients can be deaf from birth or early childhood, leading to deprivation of the auditory system, requiring cortical reorganization of the brain. Many of these patients demonstrate great neural plasticity after implantation through the enhancement of language and reading skills (Geers, 2002).

Kral and Sharma (2012) stated deprivation of auditory stimulation from birth affects the brain's ability to make sensory connections needed to develop speech and oral language learning. These researchers examined the differences in sensory stimulation in individuals receiving a cochlear implant. A cochlear implant bypasses the inner ear and can directly stimulate the auditory nerve, potentially eliminating the auditory deprivation congenitally deaf individuals experience. Children who are deaf prior to language development, if implanted early in childhood, demonstrate better speech and language skills as their brains are still maturing, compared to deaf children who are implanted in elementary school or later (Geers, 2002; Kral & Sharma, 2012). The most optimal time for implantation is no later than 3.4-4 years old, with the best results around 2 years of age or younger (Kral & Sharma, 2012). This is because the auditory pathways through the brain are still maturing, thus showing the greatest plasticity for new auditory stimulation. Children implanted after the age of 6.5 showed less success with speech and language development with their cochlear implant. This is because the cortical reorganization of the auditory pathways is more difficult as the brain matures, resulting in abnormal connections and inadequate synchrony through the auditory system. These neuronal differences lead to poorer speech and language development. Kral and Sharma

(2012) concluded if implantation is performed during a specific time period of development, better speech and language outcomes can be achieved due to the brain's plasticity and maturation abilities because the brain is "hard wired" for hearing (Kral & Sharma, 2012). Because auditory learning and neural plasticity are greatest within a specific time frame, it is critical that auditory training begin as early as possible to promote the best possible listening abilities and speech and language development (Hayes et al., 2003).

Hayes et al. (2003) performed a study examining the neural plasticity of learning-impaired children utilizing auditory training techniques. Participants included children between the ages of 8-12 years who scored one standard deviation below average in a psychoeducational test battery in one of the following categories: reading, spelling, phonological awareness or auditory processing. A control group comprised of age-matched normal-learning children was utilized for comparison. Participants from the learning disability group were then divided up into the training program group or a test/re-test control group. Children in the training group attended 35-40 one-hour auditory training sessions to improve phonological awareness, auditory processing, and language processing skills utilizing the Earobics training software. Cognitive and academic abilities were then re-measured for both the learning-impaired and control groups. Hayes et al. (2003) found children in the learning-disabled trained group improved in auditory processing abilities compared to the controls. The researchers concluded that neural plasticity at the cortical level was exhibited after utilizing Earobics training software (Hayes et al., 2003). Auditory training software programs such as Earobics prove to be an efficacious technique strengthening listening abilities in children during critical periods of development (Hayes et al., 2003).

As evident from the literature, the earlier the age of auditory training, the more efficacious the training will be on reorganizing the brain and creating new neural synapses because of the plasticity of the maturing brain (Geers, 2002; Hayes et al., 2003; Kral & Sharma, 2012). Audiologists and other health care professionals should be aware of neural plasticity and it's relation to auditory training in order to maximize the success of treatment and management approaches. These treatment and management approaches should be specific to the child's auditory weaknesses and promote best possible outcomes (Musiek et al., 2002).

Management vs. treatment. Intervention strategies for APD can vary depending on the patient's needs, diagnoses, and clinician's preferences. However, the two most widely used intervention approaches are treatment and management strategies. These approaches are broad, and can include a number of exercises, tasks, and other activities to structure therapy and treatment. The two terms are often used interchangeably; however, have two very different meanings (Keith, 1999).

Treatment is used as a remediation strategy. The main goal is to reorganize and alter the functioning and abilities of the CANS (Keith, 1999). Alternatively, management involves modifying the environment and improving the quality of the acoustic signal by utilizing compensatory strategies or altering the signal itself (Keith, 1999; Moore, 2006). Essentially, management involves working around the processing disorder, while treatment involves directly changing the abilities of the CANS. Both treatment and management strategies are utilized for APD treatment to ensure the best possible intervention outcomes (Keith, 1999; Moore, 2006).

Regardless of the approach, intervention strategies should be adaptive, meaning small changes are made over time (Keith, 1999). This will ensure the changes or improvements made are more permanent or routine, and that any modifications made to the lifestyle are more manageable for the child and family. Treatment should be adaptive in a way where difficulty levels are increased gradually, and done on a trial-by-trial basis to best suit the child's needs and ensure maximum efficacy (Moore, 2006). Because APD can present varying difficulties, intervention should also be specific to the child, and will require the implementation of these new techniques in the home, at school, and other important listening environments.

Management. After a diagnosis of APD has been made, it is important that the audiologist or health care professional follow-up with treatment and intervention techniques that are specific to the child's auditory deficits (Foli & Elsisy, 2009). As stated previously, management strategies focus on working around the auditory problems by adjusting the environment to best suit the child's needs. Management strategies typically fall into three categories: environmental and classroom modifications, signal enhancement strategies, and compensatory and academic strategies (Bamiou et al., 2006; Bellis 2002; Foli & Elsisy, 2009).

Environmental modifications. A noisy classroom coupled with background noise from items such as computers, heating or air conditioning systems, outside traffic, and activities from classrooms can decrease the quality of the signal, reducing the child's understanding of the spoken message (Bamiou et al., 2006). This is especially true for children with APD. Therefore, certain precautions can be taken to adjust the child's environment, and reduce the synergistic effects of background noise.

One suggestion to improve classroom noise levels begins with the architectural design of the building (Bamiou et al., 2006). For example, when possible, schools should be built in quiet areas away from road noise and construction to reduce outside distractions. Absorbent materials should be considered when designing classrooms. Covering hard, reflective surfaces such as concrete and tiling with carpet, drapes, acoustic tiling, and cork will reduce reverberant environments, thus enhancing the quality of the signal reaching the listener (Bamiou et al., 2006). Not only will changing the physical environment of the classroom enhance the signal of interest, but teachers can implement strategies to provide optimal listening opportunities for children with APD. Additionally, signal enhancement technology such as an FM system can help to overcome classroom size, teacher-pupil distance, and background noise, which increasing the ability of the signal to be heard, in turn facilitating understanding (Bamiou et al., 2006; Putter-Katz et al., 2002).

***Signal enhancement technology*.** In order to improve the SNR in the classroom, assistive listening devices should be utilized (Bamiou et al., 2006). The most commonly utilized assistive listening devices in classroom settings are personal or sound field FM systems. These devices receive acoustic information from a distant speaker, and transmit them directly to the listener's ear. A small microphone is worn by the teacher (or other speaker) and a transmitter then picks up the acoustic signal and converts it to frequency modulated waves, which are then sent to the receiver worn by the child (Bamiou et al., 2006). The signal can be transmitted directly to the child's hearing aid, cochlear implant, or to a set of headphones. These systems help to eliminate problems encountered by speaker-listener distance in a noisy environment by directly streaming the signal to the child's ears.

A recent study suggests FM devices improve classroom performance and psychosocial measures for children with diagnosed APD. Johnston, John, Kreisman, Hall, and Crandell (2009) conducted a study in which they fit 10 children with confirmed APD with personal FM systems. They then measured their speech perception (Hearing-in-Noise Test (HINT)), psychosocial functioning (Behavior Assessment System in Children (BASC-2)), and academic abilities (Screening Instrument for Targeting Educational Risk (SIFTER)/Learning Inventory for Education (LIFE)) before and after being fit with an FM system. During the school year, they found significant improvements in their speech perception abilities in the classroom. Improvements in academic abilities and personal achievement were also demonstrated. Most importantly, improvements in speech perception occurred with and without the use of the FM system (3.8 dB threshold improvement with FM system and 2.8 dB threshold improvement without the FM system). Johnston et al. (2009) concluded that the improvement in speech perception thresholds after FM usage suggest a change in the auditory system, indicating neural plasticity can occur with signal enhancement technology. FM systems can increase access to the auditory signal, and possibly enhance neural plasticity. However, for maximum efficacy, they should be used in conjunction with compensatory communication and listening strategies to increase understanding of verbal information (Bellis, 2002).

Compensatory strategies. Compensatory strategies are often times included in APD management plans to help the child work around their underlying auditory dysfunctions by enhancing their listening and learning skills (Bellis, 2002; Foli & Elsisy, 2010). There are several different strategies used to aid individuals in coping with auditory deficits. Among the most common include metacognitive and metalinguistic strategies and self-advocacy training (Bamiou, 2006; Chermak et al., 1998; Putter-Katz et al., 2002).

Metacognitive and metalinguistic skills are typically developed through auditory experiences. However, in individuals with APD, auditory experiences are often degraded or reduced, thus creating deficits in metacognitive and metalinguistic skills (Chermak, 1998). Metacognitive skills are necessary to improve verbal communication abilities with others. Several researchers have suggested metacognitive skills be strengthened by enhancing auditory memory, problem-solving skills, verbal rehearsal, auditory closure, and increasing motivation by being an active participant in conversation (Bamiou et al., 2006; Bellis, 2002; Chermak, 1998; Putter-Katz et al., 2002). Similarly, metalinguistic skills are necessary to strengthen spoken language comprehension (Bamiou et al., 2006; Bellis, 2002). Metalinguistic skills can be enhanced by learning basic rules of the language, learning contextual cues, and vocabulary building (Bamiou et al., 2006). Although these compensatory strategies, as well as environmental modifications, and signal enhancement technology are necessary for a child with APD to function in everyday listening environments, direct remediation of the disorder is needed to optimize successful communication.

Treatment. Direct remediation of the underlying deficits causing APD is considered auditory training (Chermak & Musiek, 2002; Foli & Elsisy, 2010). This training is often times administered by an audiologist or speech-language pathologist, and targets auditory deficits specific to the child (Chermak & Musiek, 2002). Although treatment plans should be specific to each child, general principles have been suggested to maximize efficacy.

Chermak and Musiek (2002) recommended general procedures to enhance the treatment process. They suggest treatment should be specific, and presented with increasing difficulty to maintain motivation. A minimum of 70% accuracy should be obtained in each task before increasing the difficulty level. This ensures the child is proficient and ready to move onto a more challenging task without becoming overwhelmed or overly frustrated. The treatment sessions should be conducted 5-7 times per week. Most importantly, it is crucial to set up comparative measures to track progress and efficacy of the training. This can be done by measuring the child's abilities prior to treatment, during, and after (i.e. measure improvements in listening, comprehension of spoken language, academic achievements, etc.). Surveys, inventories, and performance scales can be useful tools in determining efficacy of the training (Chermak & Musiek, 2002).

Treatment is typically conducted through bottom-up or top-down approaches, which are strategies that are used to process auditory information (Chermak & Musiek, 2002). Bottom-up approaches are stimulus-driven, where small pieces are analyzed to complete a whole message. A bottom-up approach is used to facilitate receiving an acoustic stimulus (i.e. discrimination tasks). Top-down is language-driven, where a larger concept is broken down for comprehension (ASHA, 2005). Top-down approaches are used to facilitate understanding and interpretation of the auditory stimulus by implementing linguistic rules. These two types of learning strategies are often times used in either an informal or formal auditory training manner.

Informal vs. formal training techniques. Auditory training is often times carried out in a variety of settings, and utilizes various methods to employ better listening and comprehension strategies. Two training strategies include formal and informal techniques. Formal training is typically performed in a controlled environment, such as a clinic, by an audiologist or a speech-language pathologist with guided instruction (Chermak, 2002; Bamiou et al., 2006). Formal training can involve the use of acoustically manipulated stimuli through computer technology and electroacoustic equipment (Bamiou et al., 2006; Musiek, 1999b). Informal training techniques are often times used in conjunction with formal training techniques at home for additional practice (Musiek, 1999b). Informal training is typically not as specific as formal, however, it is important to supplement skills that are developed through the use of informal training techniques, as well as strengthen basic auditory mechanisms used for comprehending more complex stimuli (Bamiou et al., 2006; Musiek, 1999b).

Informal training techniques. Informal training techniques require the use of multiple integrative functions to improve language and auditory abilities (Chermak & Musiek, 2002). This type of training is useful to apply specific skills learned through informal training, and generalize these skills to improve communication (Chermak & Musiek, 2002). Commonly utilized informal auditory training techniques include auditory discrimination tasks, prosody training, auditory directives, and auditory vigilance training (Chermak & Musiek, 2002; Musiek, 1999; Musiek et al., 2002).

Auditory discrimination involves the ability to distinguish one acoustic stimulus from another (i.e. speech, tones, phonemes) (Musiek et al., 2002). In children with APD, more specifically temporal processing deficits, their ability to differentiate between sounds such as vowels and consonants can be difficult (Chermak & Musiek, 2002; Musiek et al., 2002). Therefore, discrimination training between vowels and consonants is utilized so children can apply these listening skills in the classroom. For example, the child is asked to verbalize written vowel sounds, then to point to written vowels presented auditorily. Vowels then can be combined with consonants, where the child is asked to identify them in a consonant-vowel-consonant combination. Once the child understands the discrimination tasks, difficulty can be increased by incorporating consonant blends or other sounds acoustically similar to vowels (Chermak & Musiek, 2002).

Prosody refers to rhythm, intonation and acoustic stress of speech (Chermak & Musiek, 2002; Musiek, 1999b). The ability to attend to subtle changes in speech prosody is often times impaired in children with APD, because they have difficulty with frequency and temporal discrimination (Chermak & Musiek, 2002; Musiek, 1999b). Prosody training can be accomplished in several ways. One of the most common is to have the client identify which syllable of a word is being stressed. Sentences can also be used because the stress of different words can alter the meaning. Lastly, reading poetry aloud is often recommended as a training technique to understand temporal cues (Chermak & Musiek, 2002).

Auditory directives involve the ability to listen and comprehend a spoken message, and produce the appropriate motor task (Chermak & Musiek, 2002; Musiek, 1999b). Listening to directions auditorily is a fundamental and critical piece towards childhood development, therefore, auditory directive training is essential for young children with APD. This training can be as easy as verbalizing a list of tasks and having the child perform them in the correct sequence (i.e. "walk upstairs, turn on the light, tie your shoes."). This training approach can be increased or decreased in difficulty level, and can be performed in a variety of listening situations (Musiek, 1999b).

Auditory vigilance is the ability to attend to the auditory stimulus throughout its duration (Musiek et al., 2002). This ability can sometimes be lacking in children with APD because as discussed earlier, APD is often times associated with ADHD (Chermak et al., 1998). One way to strengthen auditory vigilance is by reading a story of interest to the child and introduce a target word or sound to pay attention to while listening to the story. This ensures that the child maintains auditory vigilance throughout the duration of task. This task can be adapted depending on the child and the level of difficulty needed.

As discussed above, informal training tasks can be flexible and adapted to the child's needs. They are used to strengthen auditory abilities that can be generalized in the classroom and everyday life, thus improving overall communicative and listening abilities. However, informal training is not as effective if formal training of specific auditory tasks is not performed (Musiek, 1999b).

Formal training. As previously mentioned, formal training is typically conducted in a clinic setting by a speech-language pathologist or audiologist. This type of training usually involves acoustically altered stimuli through the use of computer technology (Bamiou et al., 2006). Formal training most often includes tasks of frequency, temporal, and intensity discrimination (Bamiou et al., 2006; Chermak & Musiek, 2002).

Frequency discrimination training is for individuals who perform poorly on the frequency pattern test during the diagnostic APD evaluation (Chermak & Musiek, 2002). These tasks require the individual to detect varying pitches of tones (typically 5 s duration). The frequencies and durations can be varied depending on the difficulty level of the individual. Similarly, intensity discrimination training tasks can be adjusted to accommodate the abilities of the child. These tasks require the individual to determine intensity differences between similar tones (Chermak & Musiek, 2002). Lastly, temporal training tasks can be used for children who performed poorly on the duration pattern test (Chermak & Musiek, 2002). Some temporal training tasks require the child to discriminate between similar consonant-vowel sounds. Alternatively, gap detection tests can be utilized to strengthen temporal processing abilities (Chermak & Musiek, 2002). As stated previously, the formal training tasks discussed above can require the use of computers and electroacoustic equipment for administration. More recently, computer-based auditory training programs have been found to improve auditory processing abilities (Sharma, Purdy, & Kelly, 2012; Maggu &Yathiraj, 2011).

Efficacy of formal treatment with APD. Computer-based auditory training programs have recently been utilized as a common method to facilitate treatment with APD (Chermak & Musiek, 2002; Maggu &Yathiraj, 2011). There are several commonly used software programs designed to aid in the treatment of APD, which audiologists and speech-language pathologist have utilized in the clinic and recommended to patients and their parents. However, there has been some debate surrounding the efficacy of computer-based auditory training with creating global and permanent listening and processing changes in children with APD (Gillam et al., 2008; Moore, 2011).

Benefits of computer-based auditory training. Several different types of computer-based auditory training software programs have been developed to facilitate APD treatment. Each one attempts to strengthen broad auditory and language abilities and cognitive skills. The most commonly utilized include Fast ForWord, Earobics, and Phonomena (Bamiou et al., 2006; Chermak, 2002; Gillam, et al., 2008; Sharma et al., 2012).

Earobics is an adaptive 2-step game that includes a variety of auditory and language skills to improve overall cognitive abilities. Step 1 targets phonological awareness, skills for reading, spelling, auditory memory, and attention. The first step includes six games with varying levels of difficulty, and is designed for ages 4-7. Step 2 targets the same skills as step 2, however, is intended for ages 7-10, and includes greater ranges of difficulty (Bamiou et al., 2006). Similarly, Fast ForWord is also intended to improve auditory and language skills (Bamiou et al., 2006). This training is appropriate for children 4-7 years of age, and has 3 games that are designed to improve attention and auditory discrimination abilities. Lastly, Phonomena is intended to improve language abilities, auditory discrimination, and phonemic awareness. This game is intended for children 6-12 years of age. This game uses phoneme contrasts, which adaptively become more or less difficult depending on the child, in order to maintain the greatest level of efficiency (Bamiou et al., 2006). Although these three programs are commonly utilized computer-based games, there are a variety of other auditory training games developed by researchers that can be efficacious in strengthening auditory abilities in children.

Auditory training utilizing computer software can enhance not only auditory, but also language abilities (Chermak, 2002; Moore, 2011). As previously stated, language disorders can be comorbid with APD, making computer-based treatment even more efficacious to the overall cognitive development in children (Chermak, 2002; Moore, 2011). For example, Merzenich et al. (1996) conducted a study to evaluate the effectiveness of training on temporal processing abilities in children with language-learning impairments. They utilized two computer-based software programs to engage children in auditory training. The first game required the child to reproduce non-verbal sound sequences (presented auditorily) by clicking buttons on the interactive circus game. The tonal pairs presented were a range of frequencies, and the difficulty of perceiving differences between the two pairs increased adaptively. The second game included phonetic training with consonant-vowel stimuli. Two similar consonant-vowel combinations were presented with differing consonants. The child was required to determine the sequence position of the consonant vowel. For example: /ba/ vs. /da/ was presented, and the child was asked to determine the sequence of these sounds. Again, the difficulty level was adaptive. The Tallal Repetition Test, which assesses temporal processing abilities, was administered to the participants before and after training to determine efficacy of the training (Merzenich et al., 1996).

Training was conducted over a 4 week time period with 19-28 sessions lasting approximately 20 minutes. Merzenich et al. (1996) found five out of the seven participants improved in temporal processing abilities after receiving the computer-based auditory training therapy. Two children obtained or exceeded “normal” performance levels on temporal processing tasks. The same games were administered to a larger group of children (n=11) to determine if these results could be generalized to a larger population of language-learning impaired children. They found 10 out of 11 children showed improvements with temporal processing abilities post-therapy. Merzenich et al. (1996) concluded that computer-based training activities helped strengthen auditory abilities, specifically temporal processing, in children with language-learning disorders, and that the greater the number of training sessions the child received, the better the outcome measures. Because children with APD typically have co-morbid language disorders, the outcomes of this study can be applied to a greater population, including children with various auditory disabilities.

Sharma, Purdy, and Kelly (2012) evaluated the efficacy of different intervention approaches in 55 children with diagnosed APD. Children were randomly assigned to different intervention groups (discrimination training + FM, discrimination training only, language training + FM, language training only, and no treatment). Treatment was conducted over a 6- week time period, and included a one-hour formal session with an audiologist in a university clinic, as well as homework (which included more practice items of the task worked on in the clinic) each week. Each child (excluding control group) received a minimum of 12 hours of training over the 6-week period. The discrimination training group included tasks such as gap detection and frequency and intensity discrimination. These training tasks were administered through computer-based activities in the clinic. Earobics software was sent home with the children in this group for practice with phonological processing. The language-training group did not receive formal training through a computer-based therapy program, but through informal training techniques (i.e. reading aloud, asking reading comprehension questions, etc.) (Sharma et al., 2012).

Sharma et al. (2012) evaluated auditory processing, language, and reading abilities of each participant pre and post-intervention. The frequency pattern test and HINT words/sentences were utilized to evaluate auditory processing, the Clinical Evaluation of Language Fundamentals-4 (CELF-4) and the Comprehensive Assessment of Language (CASL) were utilized to evaluate language, and the Wheldall Assessment of Reading (WARP) and the Queensland University Inventory of Literacy (QUIL) were utilized to assess reading abilities. A comparison of pre and post-measures show improvements for both treatment groups, and prove the addition of an FM system is efficacious for children with APD. However, the treatment group receiving computer-based formal treatment showed improvements that the language group did not. They showed significant improvements ($p < .01$) on the QUIL (phonological awareness) after treatment (Sharma et al., 2012). Other areas showing significant improvement in the discrimination group include: frequency pattern training, conceptions and directions, sentence recall, and receptive and core language. Improvements in these areas show that computer-based treatment can be efficacious in improving various areas of auditory perception, as well as language (Sharma et al., 2012). Although the various researchers mentioned above proved computer-based auditory training to be advantageous, others have shown little to no improvement with enhancing auditory abilities (Gillam et al., 2008; Moore, 2011).

Inadequacies of computer-based auditory training. Several researchers have questioned the ability to generalize auditory and language abilities to real-world situations, as well as the functionality and usefulness of the skills developed in the computer software training (Chermak, 2002; Moore, 2011). Researchers Gillam et al.

(2008) conducted a study to determine the efficacy of Fast ForWord on language and auditory processing abilities in 216 language-impaired children ages 6-9. Participants were divided into one of four groups: Fast ForWord training, academic enrichment, computer-assisted language intervention, or individualized language intervention. All groups received 1 hour and 40 minute training sessions 5 days a week for 6 weeks. Children in the Fast

ForWord training group played seven different games aimed to enhance discrimination of tones and phonemes, and language comprehension. The academic enrichment group played computer games not specific to language or auditory abilities, but rather targeted mathematics, science and geography. The computer-assisted language intervention group participated in games from Earobics which targeted discrimination and memory of non-speech stimuli. The individualized language intervention group included activities administered by a speech-language pathologist which targeted fundamentals of language such as semantics, syntax, narratives, and phonological awareness. To compare the efficacy of the training, the CASL and a backward masking task were administered pre and post-intervention to measure language and temporal processing abilities, respectively. Gillam et al. (2008) ran a statistical analysis, which suggested children in all four conditions improved similarly in language and auditory abilities. They concluded that the computer-based language and auditory ability training software, Fast ForWord, did not improve language or temporal processing skills any more than the other three training conditions.

Similarly, Thibodeau et al., (2001) studied the efficacy of computer-based therapy treatments in improving auditory abilities and language in children with language and auditory processing impairments compared to normally-developing children. Five children, ages 5-9, were part of the experimental group, and participated in 30-60 minute therapy sessions over a 5-6 week time span utilizing the Fast ForWord computer software. A control group consisting of five children (gender and age matched) was used for comparison purposes. Children in the experimental group completed seven games in the Fast ForWord software consisting of sound and word exercises, which were tested through discrimination tasks. To determine efficacy of the training, the experimental group was tested through masking and frequency-sweep discrimination tasks. After the training was completed, there were no significant differences between the two groups. Thibodeau et al. (2001) concluded that computer-based training does not significantly improve temporal processing or language abilities in children with language or auditory impairments. They suggested that computer-based auditory training programs could potentially be more efficacious in strengthening auditory and language abilities if they were intensive and tailored to the individual child.

The efficacy of computer-based training programs is variable (Gillam et al., 2008; Merzenich et al., 1996; Sharma et al., 2012; Thibodeau et al., 2001). Researchers have suggested that computer-based training strengthens abilities important to processing auditory stimuli, but does not necessarily treat APD by creating permanent changes in the auditory cortex (Foli & Elsisy, 2010; Thibodeau et al., 2001). Other researchers have determined that the efficacy provided by computer-based treatment options is difficult to determine because there is a lack of research surrounding the area, and that the current research has targeted only children with APD and language impairments (Moore, 2011).

Statement of Purpose

It is evident from the literature that further research is needed pertaining to computer-based therapy programs as an intervention strategy for APD. Therefore, the aim of this study is to determine the efficacy, or lack thereof, of a new app-based therapy program in treating children with a variety of auditory processing impairments.

Chapter 3

Methods and Materials

Participants

Five children, ages 7;5-11;3 years old, were assessed using two clinically used tests of auditory processing (CU-APD) (dichotic double digits test (DDT) and frequency pattern test (FPT)), as well as an app-based diagnostic evaluation (AB-DE), followed by a series of application-based (app-based) therapy programs (Zoo Keeper Sky Scraper and Insane Ear Plane). This study was approved by the Towson University Institutional Review Board. Two participants were recruited from previous APD studies conducted by the principal investigator, Dr. Jennifer L. Smart. The other participants were recruited via the Towson University Hearing and Balance Center's previous patient records. Prior to collecting data, participants were given information about the study, and an informed consent and assent forms were signed. Parents completed a comprehensive case history. All participants were native English speakers.

Equipment and Materials

All participants were seen twice a week over the course of 6 weeks for therapy. Three participants (001, 002, and 003) completed therapy in a therapy room at the Towson University Institute for Well-Being (IWB) Hearing and Balance Clinic or in the Hearing and Listening Lab in Van Bokelen Hall at Towson University. Noise measurements were taken at locations not traditionally used for therapy. One participant completed therapy in a quiet, private room at the C. Burr Artz Public Library, and one participant completed therapy in a quiet, private area at the Howard County Public

Library System (HCPLS) East Columbia Branch. Using Decibel 10^{th} Sound Level Meter App, the noise levels were an average of 43.08 dB SPL at C. Burr Artz Public Library and 45.60 dB SPL at HCPLS East Columbia Branch. Each participant was asked to complete Zoo Caper Sky Scraper and Insane Ear Plane each therapy session.

A Grason-Stadler (GSI) TympStar Middle Ear Analyzer was used for immittance testing. The hearing screening and APD test battery was administered in a double-walled, sound-treated test suite utilizing a GSI two-channel clinical audiometer coupled to ER_3A headphones. These devices were calibrated to ANSI S3.6-1996 specifications.

A Sony 5 CD Disc Ex-Change System was used to present stimuli for the CU-APD test battery. The Veteran's Affairs (VA) Tonal/Speech Materials CD Disc 2.0 was used to administer the DDT and FPT. The CD was calibrated using its calibration tone. All stimuli were presented at a comfortable listening level (60 dB HL). An Apple iPad was utilized to administer the AB-DE and therapy games under Koss UR10 on-ear headphones.

Procedure

Screening tests.

The Test of Nonverbal Intelligence 3^{rd} edition (TONI-3) and the CELF-4 screening test were administered prior to the audiologic evaluation, CU-APD tests, AB-DE, and therapy sessions to determine normal cognition and language abilities. The CELF-4 screening test and TONI-3 were only administered if the child had not been administered these tests in the past 6 months.

TONI-3. The TONI-3 was administered in accordance with the instruction manual. It was completed in a quiet and well-lit environment. Scoring and pass or refer results were determined by the test manual.

CELF-4 screener. The CELF-4 screening test was administered in accordance with the administration manual. Practice items were given to the participant prior to each test section. It was completed in a quiet and well-lit environment. Scoring and pass or refer results were determined by the test manual.

Hearing screening. The hearing screening was only administered if the child had not been administered an audiologic evaluation in the past 6 months. Otoscopy was completed for both ears to ensure clear external ear canals and visually intact tympanic membranes. Immittance testing, which includes 226 Hz tympanometry and acoustic reflex testing (ART), was then administered. Jerger Type A tympanograms were obtained prior to data collection. Contralateral and ipsilateral ARTs were tested at 500, 1000, and 2000 Hz, bilaterally. ARTs were obtained using routine clinical procedures by starting at 80 dB HL and increasing in 5 dB HL increments until a threshold was determined (0.2ml and growth in the following response). Participants received an air conduction hearing screening in both ears at 15 dB HL at octave test frequencies between 250-8000 Hz.

CU-APD. Pass/fail criteria for the FPT and DDT was based off of the normative data collected for the VA Tonal/Speech Materials CD Disc 2.0 (DDT and FPT) (McDermott et al., 2016). Test stimuli for the DDT and FPT was administered at a comfortable listening level (60 dB HL).

DDT. Five practice items were administered prior to the actual test items. Twenty, two-digit pairs were administered to the right and left ears simultaneously. The participant was instructed to repeat all four numbers heard in any order. Scores were calculated for each ear. The total number of correct test items was divided by 40 and multiplied by 100 to get the percent-correct score per ear.

FPT. Five practice items were administered prior to the actual test items. The participant heard 15 patterns of three tones. The tones were either a low pitch (880 Hz) or a high pitch (1122 Hz). Each ear was presented with 15 different patterns and tested individually. The participant repeated the pattern heard by stating “high” or “low”. Scores for each ear were calculated separately. The total number of correct items were divided by 15 and multiplied by 100 to get the percent-correct scores.

AB-DE. All participants completed the 30-minute diagnostic evaluation utilizing the Acoustic Pioneer app. Pass/fail criteria for the app-based APD evaluation was based off of the normative data collected by the creators of Acoustic Pioneer. To qualify for this study, participants had to score either two or more subtests in the “mild weakness” range, or in the “significant weakness” range on one or more subtests. The activities on the app-based APD evaluation were administered at a comfortable listening level via an Apple iPad (50% of the full-on volume).

The diagnostic portion of the app included 10 subtests that claimed to assess areas of temporal processing, dichotic listening, lateralization and localization, and monaural low redundancy abilities. These subtests were divided into linguistic (5 subtests) and non-linguistic (5 subtests) areas. The app did not administer all 10 of the subtests to children under the age of 8 because these subtests targeted areas of the brain still maturing (M. Barker, personal communication, December 3, 2015). Table 1 displays which tests are administered to children 5-7 years of age, and which are administered to children ≥8. After the AB-DE was completed, the app compared results to its own normative data, and generated a report outlining specific auditory weaknesses (i.e. normal results, mild weakness, or significant weakness). The generated report then gave recommendations for therapy approaches.

Table 1

Differences in Non-Linguistic vs. Linguistic Subtests Administered in the Acoustic Pioneer Diagnostic Evaluation by Age

Non-Linguistic	Ages 5-7	8+	Linguistic	Age 5-7	8+
Hearing Screening and lateralization		x	Word Memory	x	x
Tonal Pattern Temporal Processing		x	Rapid Speech	x	x
Tonal Pattern Memory		x	Dichotic Words	x	x
Rapid Tones		x	SPIN w/o Localization	x	x
Dichotic Sounds	x	x	SPIN w/ Localization	x	x

Note. SPIN = Speech in Noise.

Therapy activities. Participants completed therapy sessions twice a week for 6 weeks, for a total of 12 therapy sessions. Each therapy activity lasted approximately 15-20 minutes each. No Participant was engaged in therapy for more than 45 minutes in duration. Progress for each participant was recorded from the app-generated report.

Insane ear plane. All participants engaged in therapy app regardless of their results on the CU-APD tests outlined above. The therapy included the Insane Ear Plane app on the Apple iPad with the volume set to 50% maximum. This app tracked each participants' improvements separately, and progressed at a pace that suited the abilities of the participant. Insane Ear Plane utilized interactive games and activities aimed at improving tonal listening and processing skills. The app progressed through various activities (games) aimed at strengthening auditory memory, pitched tones, and frequency sweeps. The child followed directions given by the app's "host" (a cartoon bird) to complete each activity. Each activity varied slightly. For example, in one activity, the child was "flying" a plane, and was asked to touch the side of the screen where they heard the tone (the tone is presented in a different frequency each presentation) in order to correctly navigate the plane. Another task required the child to identify the direction of a tonal sweep, which presented from either right to the left of left to right. The child swiped their finger in the correct direction.

Zoo caper sky scraper. All participants engaged in this therapy app regardless of their results on the APD tests outlined above. The therapy included the Zoo Caper Sky Scraper app on the Apple iPad with the volume set to 50% maximum. This app tracked each participants' improvements separately, and progressed at a pace that suited the abilities of the participant. This therapy app utilized interactive games and activities that were aimed at improving dichotic listening abilities. This therapy app introduced animal sounds to each ear and required the listener to correctly identify which animal was making the sound. The activity stayed essentially the same, but increased in difficulty gradually. For example, lower levels of this activity only had a few animals to choose from, and only one animal was presented to each ear at a time. Higher levels of the game introduced more animal sounds, and eventually introduced two animal sounds to each ear at the same time, with the inter-stimulus-interval between each presentation of the animal sounds getting progressively shorter.

Post-treatment evaluation. Following the 6 week therapy sessions (or less, depending on the participants progression through the application), each participant was re-screened via the CU-APD tests (DDT and FPT) and the AB-DE. The same procedures for administration were followed as outlined above.

Summary score sheet. The parents/guardians of the participants were given a summary sheet after testing was complete. The summary sheet provided an explanation of the auditory processes assessed, as well as the therapy activities. The summary sheet indicated which auditory processes their child improved upon following therapy, as well as their scores pre and post-therapy. See Appendix E.

Exclusion criteria. Participants were excluded if: under the age of 7 years, or over the age of 12 years, 11 months, hearing thresholds >15 dB HL across at any of the test frequencies, Jerger type B tympanograms with small or normal ear canal volume and without patent P.E. tubes, or Jerger type C tympanograms, absent or elevated ipsilateral and/or contralateral ARTs across all frequencies, and/or a nonverbal IQ score of <80 on the TONI-3, or a referral score of on the CELF-4.

Statistical Analysis

The goal of this pilot study was to determine if an app-based therapy program improved auditory abilities in children with diagnosed or suspected APD. An exact McNemar test was performed to examine differences in pre and post-therapy test results for the AB-DE and the CU-APD tests. An alpha value of 0.05 was used to determine significance.

Chapter 4

Results

Participants

Five participants with suspected or confirmed diagnosis of APD participated in this study. Participants included 4 males and 1 female, ages 7.50 to 11.33 years (*M* = 9.77, *SD* = 1.69). Two had a known diagnosis of APD, and three were suspected of having APD. Table 2 displays the demographics for the participants. Data were analyzed using Microsoft Excel 2013 and SPSS Statistics version 23.

Table 2

Demographics of Participants

Participant	Gender	Age (years; months)
001	Male	9;8
002	Female	11;4
003	Male	7;6
004	Male	9;6
005	Male	10;9

Case history. According to parent reports, additional diagnoses reported included: dyslexia (*n* = 1), learning disability (*n* = 2), ADHD (*n* = 2), and/or a language delay (*n* = 1). All four participants had at least one additional diagnosis, while two participants had two additional diagnosed disorders. All participants spoke English as their primary language. Two participants were left-handed. A majority of participants

(80%) reported playing a musical instrument. No complications during delivery were reported for all participants. However, for one participant, hydronephrosis was diagnosed in utero. Two participants had a history of ear infections, one received pressure equalization (P.E.) tubes, and one had a tonsillectomy. None of the participants were receiving treatment for APD at the time of this study.

Additional Assessment Measures

TONI-3 and CELF-4. All participants passed the language screening (CELF-4 screener) and nonverbal IQ (TONI-3) test. The scaled score results for the TONI-3 ranged from 93 to 100 (M = 96.6, SD = 2.97) for the five participants. All of the participants scored at or above the respective age criterion score on the CELF-4 screening test. Scaled scores for the TONI-3 and the "normal range" for scores are displayed in Table 2. Additionally, criteria scores for each participant and age-matched norms for the CELF-4 screening test are also displayed in Table 3.

Table 3

Individual Participant Test Scores for the Additional Assessments and Age-Matched Norms

	TONI-3	Norm Range	CELF-4	Age Norm
Participant				
001	98		18	≥17
002	100	85-115	22	≥19
003	94		21	≥16
004	98		31	≥17
005	93		24	≥18

Note. Test of Nonverbal Intelligence, 3rd Edition (TONI-3), Clinical Evaluation of Language Fundamentals, 4th Edition Screening Test (CELF-4).

Peripheral Hearing Assessment. For two participants, otoscopy revealed essentially clear external auditory canals with visually intact tympanic membranes, bilaterally. Two participants had minimal cerumen in the external auditory canals, and one participant had visible P.E. tubes, bilaterally. Four of the participants had normal peripheral hearing sensitivity, bilaterally, as measured by an air conduction pure tone screening at 15 dB HL across octave frequencies from 250-8000 Hz. Participant 001 had a slight low frequency hearing loss from 250-1000 Hz in the left ear. Due to this asymmetry and failure on the hearing screening and localization subtest on the AB-DE, he was excluded from further data analysis.

Word recognition testing at 40 dB HL SL re: pure tone average revealed average word recognition scores (WRS) of 100% for the right ear and 99% for the left ear. All participants had Jerger Type A tympanograms, bilaterally. All participants had measureable ARTs at 500, 1000, and 2000 Hz. Means and standard deviations for the four participants' ARTs in the ipsilateral and contralateral conditions are displayed in Table 4.

Table 4

Means and Standard Deviations of Acoustic Reflex Thresholds (ARTs) in the Ipsilateral and Contralateral Conditions for the Right and Left Ears (n = 4)

	Right Ear			Left Ear		
	500 Hz	1000 Hz	2000 Hz	500 Hz	1000 Hz	2000 Hz
Ipsilateral	88.75 (2.50)	87.50 (5.00)	91.25 (6.29)	92.50 (6.45)	88.75 (6.29)	90 (7.07)
Contralateral	93.75 (4.88)	95 (0.00)	91.25 (2.5)	98.75 (2.50)	91.25 (4.79)	87.5 (5.00)

Note. Mean ARTs reported in dB HL; standard deviations are reported in parenthesis.

Therapy Results

Completion progress for each participant are displayed in percentages in Table 5 and Figure 1 for Zoo Caper Sky Scraper. Two participants (002 and 003) completed Zoo Caper Sky Scraper (i.e.100% completion) prior to completing the 6-week therapy sessions. Participant 002 completed Zoo Caper Sky Scraper at the fourth therapy session, while participant 003 reached completion after the second therapy session. The final two participants only reached 83% completion at the 6 week mark.

The progress for each participant for Insane Ear Plane is displayed in Table 6. Two participants achieved >75% completion and 2 participants achieved <50% completion. Of note, participant 002 made zero progress for the duration therapy. None of the participants completed Insane Ear Plane during the 6 weeks of therapy (Figure 2).

Table 5

Zoo Caper Sky Scraper Progress Completion for Each Participant for 12 Therapy Sessions

	Participant			
Session #	002	003	004	005
1	50%	50%	50%	33%
2	67%	100%	67%	50%
3	83%		67%	67%
4	100%		67%	67%
5			67%	83%
6			67%	83%
7			67%	83%
8			83%	83%
9			83%	83%
10			83%	83%
11			83%	83%
12			83%	83%

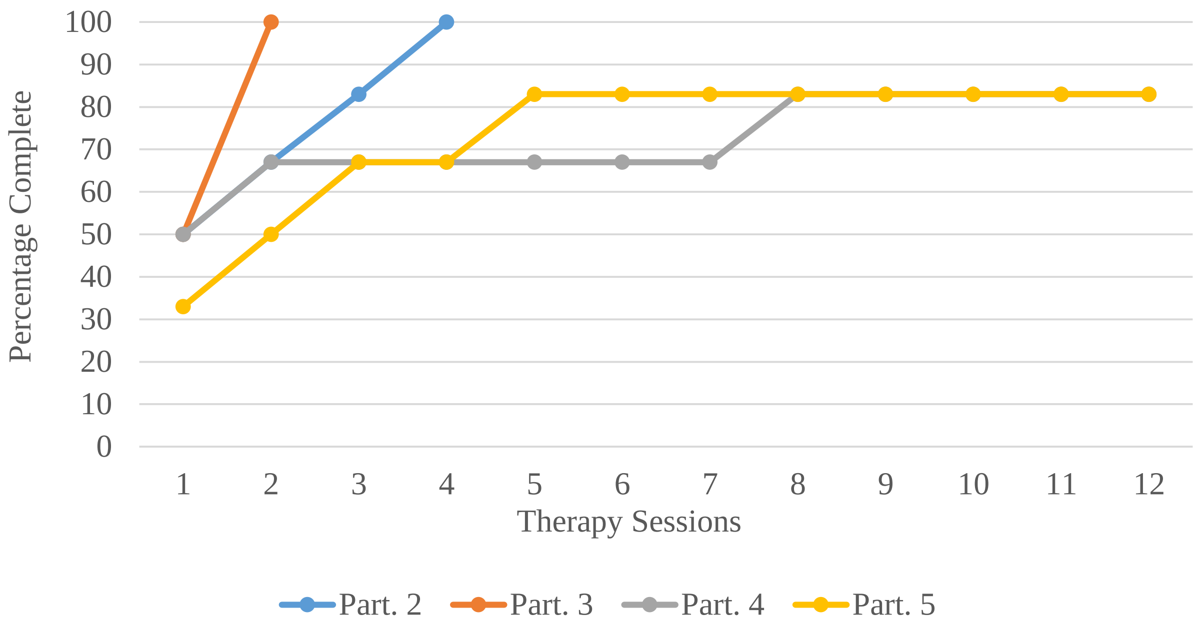


Figure 1. Zoo Caper Sky Scraper completion progress over 12 therapy sessions for each participant. Part. = Participant.

Table 6

Insane Ear Plane Progress Completion for Each Participant for 12 Therapy Sessions

	Participant			
Session #	002	003	004	005
1	20%	0%	10%	10%
2	40%	0%	20%	10%
3	40%	0%	50%	40%
4	40%	0%	60%	40%
5	40%	0%	80%	60%
6	40%	0%	90%	60%
7	40%	0%	90%	60%
8	40%	0%	90%	60%
9	40%	0%	90%	60%
10	40%	0%	90%	70%
11	40%	0%	90%	80%
12	40%	0%	90%	80%

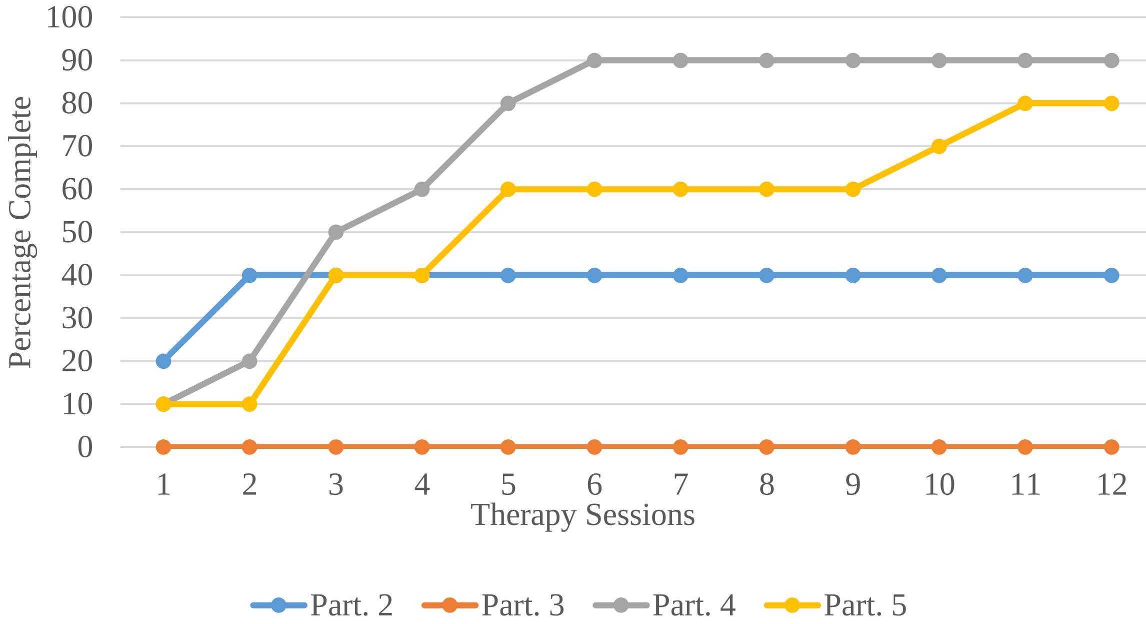


Figure 2. Insane Ear Plane completion progress over 12 therapy sessions for each participant. Part. = participant.

AB-DE: Pre vs. Post-Therapy

As noted previously, because the youngest participant (003) was below the age of 8, the diagnostic portion of the app only administered 1/5 of the non-linguistic subtests. Therefore, participant 003 was not included in data analysis for the "non-linguistic" subtests (excluding dichotic sounds). The AB-DE was administered to the participants before and after the 6 week therapy sessions. Scores for each subtest in the AB-DE were given categorically (normal result, significant weakness, mild weakness). All participants had at least one area of auditory processing of "significant weakness" prior to therapy. A summary of pre and post-therapy scores are displayed in Appendix F. Overall, more participants scored "normal" results (84.8%) versus "abnormal" (15.2%) results post-therapy. Three participants scored "abnormal" results post-therapy and "normal" results pre-therapy on one subtest each. “Abnormal” is the term used for a “mild weakness” or “significant weakness” in this study.

Results on the Hearing Screening and Localization and Tonal-Pattern Temporal Processing subtests for the AB-DE were within normal limits pre and post-assessment (*n* = 3). Figure 3 displays scores for Tonal-Pattern Memory (TPM) subtest for the app-based diagnostic evaluation (*n* = 3). One participant’s score went from normal to significant weakness, and another participant’s scores were normal and remained normal. The third participant’s score went from significant weakness to normal.

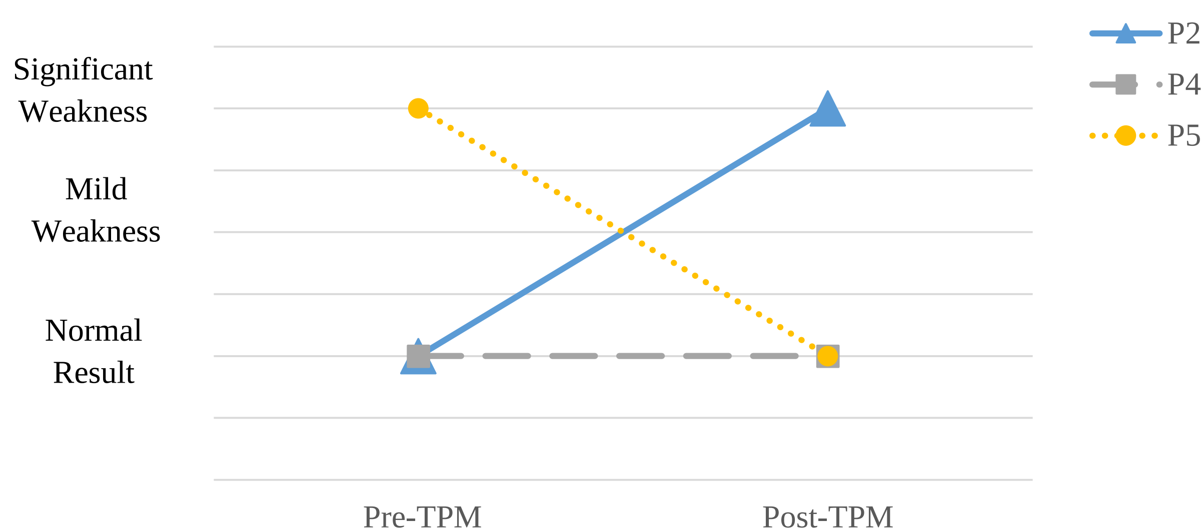


Figure 3. Pre and post-therapy scores for each participant for the Tonal-Pattern Memory (TPM) subtest on the app-based diagnostic evaluation. P = participant. *n* = 3.

Figure 4 displays scores for the Rapid Tones (RT) subtest for the AB-DE *(n* = 3). This figure shows two participants scored “normal results” in both the pre and post-therapy conditions. Participant 005 scored a “normal result” in the pre-therapy condition, and a “significant weakness” post-therapy.

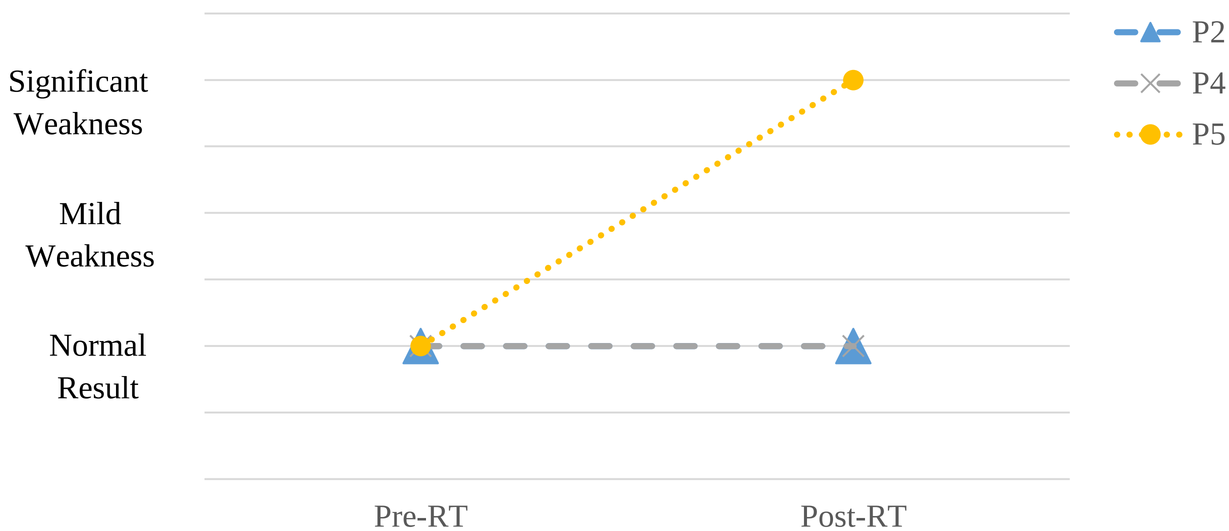


Figure 4. Pre and post-therapy scores for each participant for the Rapid Tones (RT) subtest on the app-based diagnostic evaluation. P = participant. n = 3.

Figure5 displays scores for the Dichotic Sounds (DS) subtest for the AB-DE (n = 4). This figure shows all participants scored a “normal result” in the post-therapy condition. However, participants 002 and 005 scored “mild weaknesses” in the pre-therapy condition, while participants 003 and 004 scored “significant weaknesses” in the pre-therapy condition.

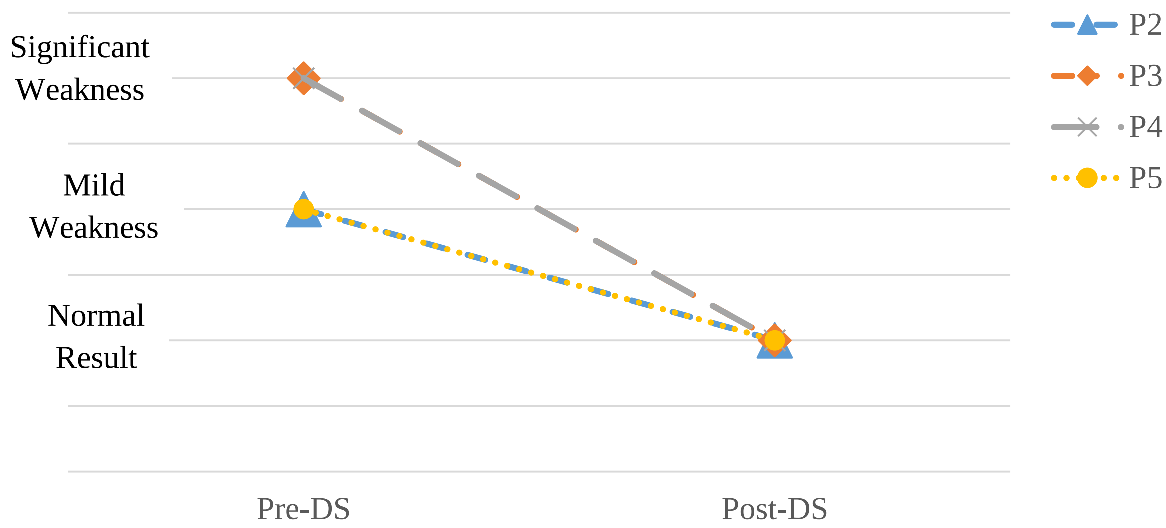


Figure 5. Pre and post-therapy scores for each participant for the Dichotic Sounds (DS) subtest on the app-based diagnostic evaluation. P = participant. *n* = 4.

Figure 6 displays scores for the Word Memory (WM) subtest for the AB-DE (*n* = 4). This figure shows participants 002 and 005 scored "normal results" in both the pre and post-therapy conditions. Participant 003 scored a "normal result" in the pre-therapy condition, and a "significant weakness" post-therapy. Participant 004 scored a "mild weakness" in the pre-therapy condition, and a "normal result" in the post-therapy condition.

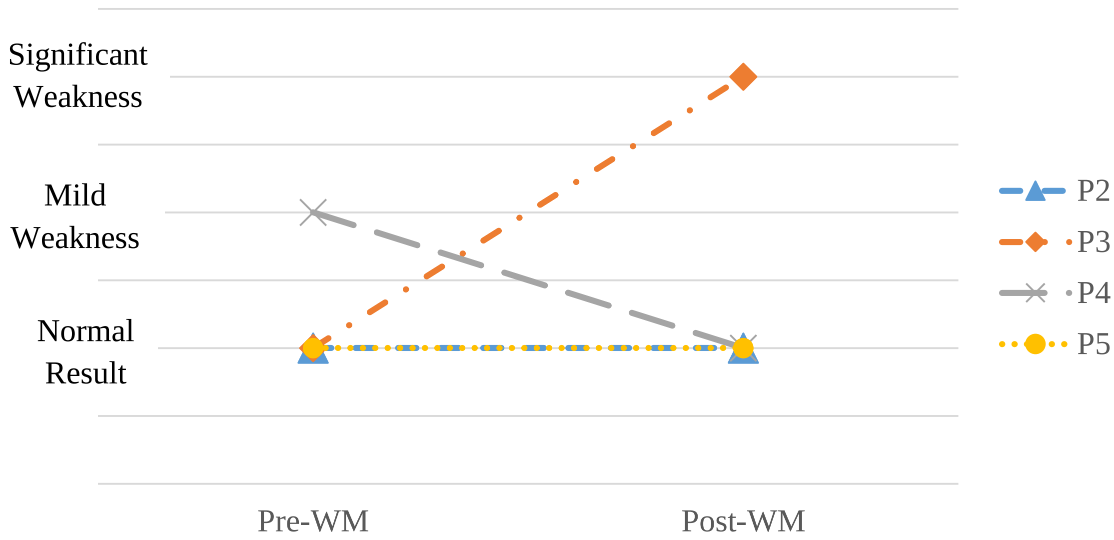


Figure 6. Pre and post-therapy scores for each participant for the Word Memory (WM) subtest on the app-based diagnostic evaluation. P = participant. *n* = 4.

Figure 7 displays scores for the Rapid Speech (RS) subtest for the AB-DE (*n* = 4). This figure shows two participants scored "normal results" in both the pre and post-therapy conditions. Participant 002 scored a "normal result" in the pre-therapy condition, and a "significant weakness" post-therapy. Participant 005 scored a "significant weakness" in the pre-therapy condition, and a "mild weakness" in the post-therapy condition.

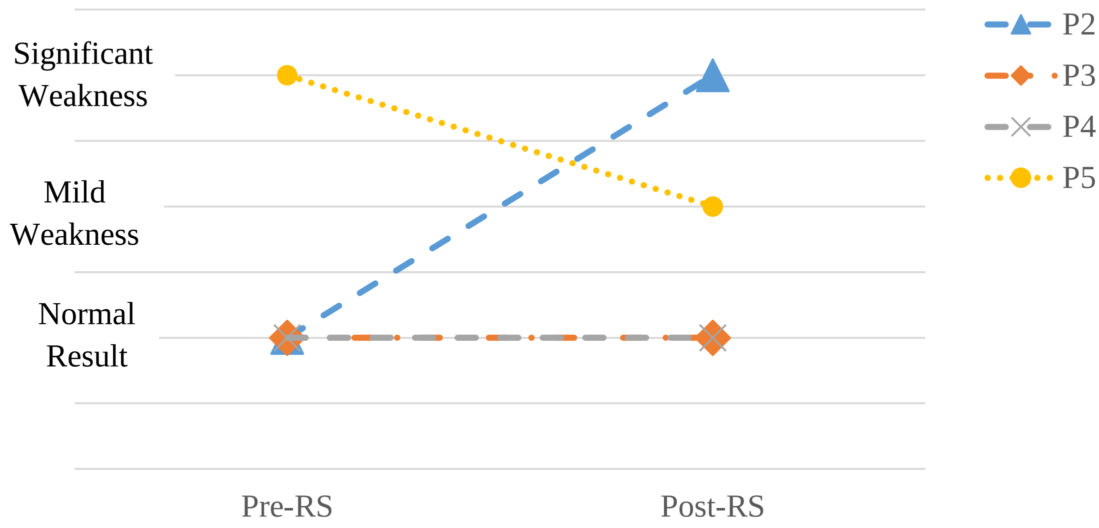


Figure 7. Pre and post-therapy scores for each participant for the Rapid Speech (RS) subtest on the app-based diagnostic evaluation. P = participant. *n* = 4.

Figure 8 displays scores for the Dichotic Words (DW) subtest for the AB-DE (*n* = 4). This figure shows all participants scored a "normal result" in the post-therapy condition. Three participants scored "significant weaknesses" in the pre-therapy condition, while participant 005 scored a "mild weakness" in the pre-therapy condition.

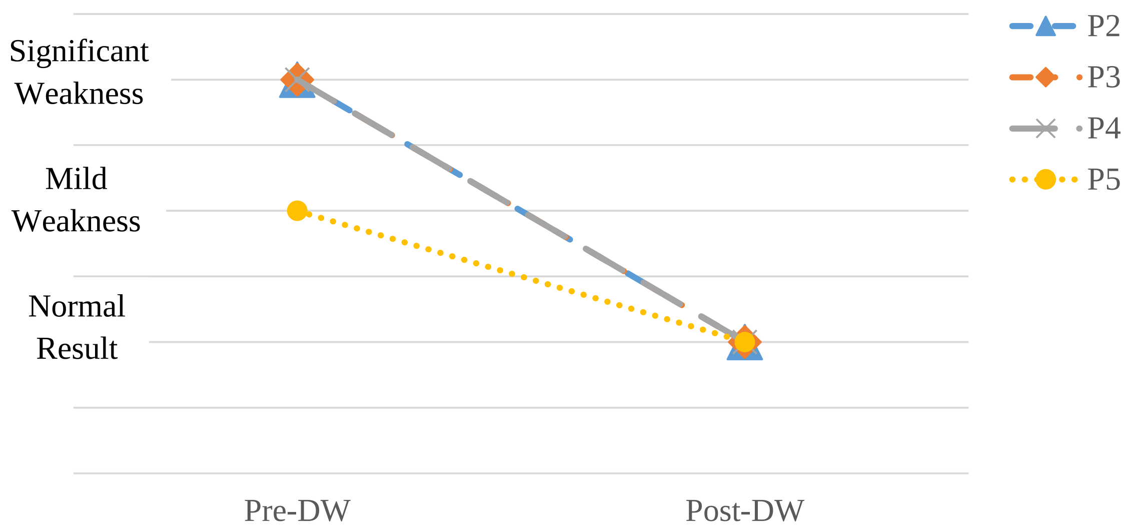


Figure 8. Pre and post-therapy scores for each participant for the Dichotic Words (DW) subtest on the app-based diagnostic evaluation. P = participant. *n* = 4.

Figure 9 displays scores for the Speech-in-Noise (SPINW/O) without Localization Cues subtest for the AB-DE (*n* = 4). This figure shows all participants obtained the same score in the pre and post-therapy conditions. Participants 002, 003, and 004 scored a “normal result” in the pre-therapy and post-therapy conditions. Participant 005 scored a “mild weakness” in both the pre-therapy and post-therapy conditions. Lastly, results on the Speech-in-Noise with Localization Cues subtest were within normal limits for all participants at pre and post-therapy assessments.

Figure 9. Pre and post-therapy scores for each participant for the Speech-in-Noise without Localization Cues subtest on the app-based diagnostic evaluation. P = participant *n* = 4.

An exact McNemar's test was performed on scores from each subtest to determine if therapy had a significant effect on auditory processes assessed in the AB-DE. All effects were reported as significant at $p < .05$ unless otherwise stated. Results of the exact McNemar's test revealed no statistically significant differences in scores pre vs. post-therapy for any of the non-linguistic subtests (hearing screening/lateralization, tonal-pattern temporal processing, tonal-pattern memory, rapid tones (n = 3) dichotic sounds (n = 4)) $p > .05$. Similarly, no statistically significant difference in scores pre vs. post-therapy was found for the linguistic subtests (word memory, rapid speech, dichotic words, and speech-in-noise with and without localization cues (n = 4)) $p > .05$. Exact significance values for each subtest determined using the McNemar's test are displayed in Table 7.

Table 7

Exact McNemar's Significance Values for each Subtest of the App-Based Diagnostic Evaluation

	Sig. (2-tailed)
Non-Linguistic Areas	
Hearing Screening and Lateralization	1.00
Tonal-Pattern Temporal Processing	1.00
Tonal-Pattern Memory	1.00
Rapid Tones	1.00
Dichotic Sounds	0.25
Linguistic Areas	
Word Memory	1.00
Rapid Speech	1.00
Dichotic Words	0.25
Speech-in-Noise (No localization cues)	1.00
Speech-in-Noise (With localization cues)	1.00

Note. An alpha value of .05 was used to determine significance. For hearing screening/lateralization, tonal-pattern temporal processing, tonal-pattern memory, and rapid tone subtests n =3. All other subtests n = 4.

CU-APD

Raw test scores for the DDT and FPT pre and post-therapy for each participant can be found in Tables 8 and Table 9, respectively. For the DDT, two participants failed in the left ear only (004 and 005), and one failed in both ears (003) pre-therapy. Post-therapy, two participants failed in the left ear only (003, 005). For the FPT, three participants failed in both the right and left ears pre and post-therapy (002, 003, 005).

Table 8

Individual Participant Test Scores for the Dichotic Double Digits Test (n = 4)

	Pre-Therapy		Post-Therapy	
Participant	Right	Left	Right	Left
002	95	90	100	87.5
003	*72.5	*62.5	87.5	*62.5
004	92.5	*70	95	85
005	93	*65	97.5	*72.5

Note. Scores are reported in percentages. * indicates a score below normal limits.

Table 9

Individual Participant Test Scores for the Frequency Pattern Test (n = 4)

	Pre Therapy		Post Therapy	
Participant	Right	Left	Right	Left
002	*46.67	*33.33	*26.7	*40
003	*20	*20	*20	*26.7
004	87	73	80	86.7
005	*73.33	*66.67	*73.33	*73.33

Note. Scores are reported in percentages. * indicates a score below normal limits.

Dichotic Double Digits Test and Frequency Pattern Test pre and post-therapy. Percentage scores for the DDT pre-therapy ranged from 72.5% to 95% (*M* = 88.25, *SD* = 10.56) and from 62.5% to 90% (*M* = 71.87 *SD* = 12.48) for the right and left ears, respectively Percentage scores for the DDT post-therapy ranged from 87.5% to 100% (*M* = 95, *SD* = 5.40) and from 62.5% to 87.5% (*M* = 76.88, *SD* = 11.61) for the right and left ears, respectively. For the FPT, percentage scores pre-therapy ranged from 20% to 87% (*M* = 56.75, *SD* = 29.68) and from 20% to 73% (*M* = 48.25, *SD* = 25.64) for the right and left ears, respectively. Percentage scores for the FPT post-therapy ranged from 20% to 80% (*M* = 50.01, *SD* = 31.02) and from 20.67% to 86.7% (*M* = 56.68, *SD* = 28.02) for the right and left ears, respectively.

An Exact McNemar's test was performed on scores for the FPT and DDT to determine if there were significant changes to scores pre vs. post-therapy. All effects were reported as significant at $p < .05$ unless otherwise stated. Results of the exact McNemar's test revealed no statistically significant difference in scores pre vs. post-therapy for both the FPT and DDT for either the right or left ears (n = 4) $p > .05$. Exact significance values for each subtest determined using the Exact McNemar's tests are displayed in Table 10.

Table 10

Exact McNemar's Significance Values for the Frequency Pattern Test (FPT) and Dichotic Double Digits Test (DDT) by Ear (n = 4)

Test	Sig. (2-tail)
FPT - Right	1.00
FPT - Left	1.00
DDT - Right	1.00
DDT - Left	1.00

Note. An alpha value of .05 was used to determine significance. FPT = Frequency Pattern Test. DDT = Dichotic Double Digits Test.

Chapter 5

Discussion

The present study investigated the efficacy of an app-based therapy for children with diagnosed or suspected APD. No statistically significant post-therapy improvements were found on the AB-DE or the CU-APD test scores. Due to the small sample size, a case by case evaluation of results was conducted. Several themes were observed between participants. However, there are several limitations of the current study that may have impacted the evaluation of the efficacy of the therapy apps. There is, however, potential value in app-based therapies in the treatment of APD. These factors will be discussed further in this chapter. To fully explore the intricacies of the results on this small sample, each participant is discussed individually

Case Study 1: Participant 001

This participant had a mild, asymmetrical sensorineural hearing loss, and therefore, his results were not included in data analysis. This is because the AB-DE and therapy games were normed on children with symmetrical hearing of 20 dB HL or better (M. Barker, personal communication, February 5, 2016). Accurate conclusions on the efficacy of this therapy for this participant could not be made.

Case Study 2: Participant 002

Participant 002 was the oldest participant (11;4) in the study, and the only female. She entered the study with a diagnosis of APD, with specific deficits found in temporal processing. She also has a diagnosis of a learning disability, however, she passed the cognitive screener (TONI-3) and language screener (CELF-4), and therefore continued in the study. Overall, this participant made little progress in the app-based therapy activity that specifically targeted temporal processing abilities. Additionally, this participant made minimal improvements, if any, on both the AB-DE and CU-APD tests post-therapy. A more detailed interpretation of therapy results and re-evaluation measures will be explored next.

Therapy results. Participant 002 completed the Zoo Caper Sky Scraper therapy app in four sessions (two weeks). For the Insane Ear Plane therapy app, she improved to 40% completion by her second session (end of first week). However, she plateaued at this point because for the rest of therapy, she remained at 40% complete.

The plateau observed early on in the Insane Ear Plane therapy app for this participant indicates the potential need for an increase in the frequency of therapy and/or the addition of another type of therapy targeting the same auditory skill (Bellis & Anzalone, 2008). This concept is supported by several researchers who suggest that in order for APD therapy to be maximally effective, the therapy must be frequent, intense, and challenging in order to make neurophysiologic changes that lead to functional improvements in auditory abilities (Bellis, 2002; Bellis & Anzalone, 2008; Chermak & Musiek, 2002; Musiek et al., 2002).

This finding could also indicate a potential flaw in the app's design, which is stated to treat temporal processing difficulties (Barker & Purdy, 2015). Perhaps when a person's progress plateaus for a certain period of time, the app could recognize the lack of improvement, and alter the activities in a way to facilitate further training.

Re-Evaluation measures.

Dichotic listening. Participant 002 showed mild to significant weaknesses in the dichotic sounds and words subtests of the AB-DE testing pre-therapy. On the contrary, she passed the DDT of the CU-APD pre-therapy. She completed the Zoo Caper Sky Scraper therapy app in two weeks, possibly indicating that there wasn't actually a deficit in that area as the AB-DE tests indicated. Both the AB-DE and the CU-APD post-assessments revealed normal dichotic listening abilities. This individual's results highlights that the AB-DE and the CU-APD results may conflict in determining areas of auditory weaknesses for dichotic listening and should be evaluated in a larger scale study.

Temporal processing. Participant 002's results for the AB-DE of tonal-pattern temporal processing and tonal speed were within normal limits pre and post-therapy but she was below normal limits for the FPT of the CU-APD pre and post-therapy. Her scores for the FPT pre-therapy were 46.7% and 33.33% for the right and left ears, respectively. Post-therapy, her FPT scores were 26.7% and 40% for the right and left ears, respectively. This finding indicates that the therapy did not impact her temporal processing abilities after 6 weeks of training as measured by the FPT. This finding was not surprising considering the participant did not progress past 40% completion on the Insane Ear Plane therapy app. Poor performance on the FPT and the challenge she faced with the tonal-processing app-based therapy are in direct conflict with the AB-DE testing, which found her temporal abilities within normal limits pre-therapy. Following the therapy, normal results were found on the AB-DE tests for temporal processing and her scores on FPT remained constant (in the "outside normal limits" range). It appears from this person's findings that the CU-APD and the AB-DE conflict in accurately determining areas of auditory weakness for temporal listening. The FPT has been found to be the most sensitive and specific test commonly utilized in the APD test battery, therefore it is concerning when the AB-DE failures are not backed up by the FPT results (Musiek et al., 2011; Musiek & Pinheiro, 1983).

Case Study 3: Participant 003

Participant 003 was the youngest participant (7;6). He had a previous diagnosis of APD, with specific deficits from his previous assessment found in temporal and dichotic listening. Additionally, his parent reported a learning disability and language delay. He passed the language screening (CELF-4) and cognitive screening (TONI-3) and therefore was included in our study. Similar to participant 002, he made little progress in Insane Ear Plane despite temporal processing being a documented area of weakness for him. Additionally, this participant made minimal improvements, if any, on AB-DE and the CU-APD tests. A more detailed interpretation of therapy results and re-evaluation measures will be explored next.

Therapy results. Participant 003 completed Zoo Caper Sky Scraper in just two sessions (one week of therapy). Surprisingly, he made no progress for the Insane Ear Plane therapy app. His first session ended at 0% complete, and he remained at 0% for the entire 6 weeks.

The lack of progression observed for Insane Ear Plane indicates the potential need for an increase in the frequency of therapy or it may also indicate that the therapy is not appropriate for this person's auditory processing weakness (Bellis, 2002; Bellis & Anzalone, 2008; Chermak & Musiek, 2002; Musiek et al., 2002). As previously stated, this finding could also indicate a potential flaw in the app's design, which is stated to treat temporal processing difficulties (Barker & Purdy, 2015).

The app would stop and re-instruct the child when it believed he was simply touching the screen, which was commonly observed with this participant. However, the app never changed *how* it administered the instructions and it did not modify the wording of the directions. Additionally, the app never altered the activity, and instead gave the same instructions for the same activity over and over again, despite 0% progress. From a subjective standpoint, this appeared to be frustrating for the participant, and subsequently resulted in minimal effort during his therapy sessions.

Re-Evaluation measures.

Dichotic listening. Participant 003 showed a significant weaknesses in the dichotic sounds and words subtests of the AB-DE testing pre-therapy. Additionally, he failed the DDT of the CU-APD pre-therapy for his age (72.5% and 62.5% for right and left ears, respectively). However, he completed Zoo Caper Sky Scraper therapy app in one week. The rapid completion of therapy likely indicates that the app may not have been at the appropriate level of difficulty for the child's dichotic listening weakness. Interestingly, the AB-DE post-assessments revealed normal dichotic listening abilities. However, for the CU-APD testing, this participant passed the DDT in his right ear (87.5%) and failed in his left ear (62.5%) post-therapy.

It is highly unlikely that this participant's dichotic listening abilities improved to within normal limits following one week of treatment, as indicated by the AB-DE post-therapy assessment. Especially because this participant failed the DDT in his left ear post-therapy, which is a classic result for a dichotic listening deficit in a child under 10 years of age (Musiek, 1983). As discussed in the literature review, the DDT has both a high sensitivity and specificity in accurately identifying dichotic listening deficits

(Musiek et al., 2011). The rapid completion of the therapy app and the normal results on the post-therapy AB-DE are problematic for the future clinical utility of the therapy-app. This finding indicates that the AB-DE could mislead an audiologist regarding diagnosis and/or treatment of deficits.

Temporal processing. Because participant 003 was younger than 8 years of age, the AB-DE does not include an assessment of temporal abilities. Therefore the only re-evaluation measure for temporal processing was the CU-APD test (FPT). As noted previously, subtests administered in the AB-DE for under 8 examined dichotic listening, auditory memory and closure, and speech in noise abilities (Barker & Purdy, 2015). Therefore, a comparison of temporal processing abilities pre- and post-therapy via the AB-DE was not possible. However, comparisons pre and post-therapy can be made utilizing the CU-APD tests.

His scores for the FPT pre-therapy were 20% for both ears. Post-therapy, his FPT scores were 20% and 26.7% for the right and left ears, respectively. Pre and post-therapy scores for the FPT show no improvements, indicating that therapy did not affect temporal processing abilities which was expected because Participant 003 made 0% progress on the Insane Ear Plane app.

Case Study 4: Participant 004

Participant 004 was suspected of having APD by his mother and teachers, but did not have a formal diagnosis when he entered the study. His mother reported a previous diagnosis of ADHD and anxiety disorder. His mother reported that he took medication daily to manage his ADHD. This participant passed the cognition (TONI-3) and language (CELF-4) screeners. He failed the DDT (left ear only) from the CU-APD tests and failed two sub-tests for dichotic listening in the AB-DE supporting a possible dichotic weakness. He was within normal limits for the FPT and on the temporal processing subtests on the AB-DE pre and post-therapy. This participant made the most consistent progress in therapy when compared to the other participants. Overall, improvements were observed in both the CU-APD tests and AB-DE post-therapy for dichotic listening. A more detailed interpretation of therapy results and re-evaluation measures will be explored next.

Therapy results. Participant 004 did not reach 100% completion for Zoo Caper Sky Scraper or Insane Ear Plane therapy apps over the course of therapy. However, he did make consistent progress for the Insane Ear Plane therapy app. He gradually improved from 10% completion after the first session to 90% completion at the last session. However, it was observed that he remained at 90% completion for sessions 6 through 12 (the last 3 weeks of therapy). Completion progress for Zoo Caper Sky Scraper therapy app also progressed steadily. For Zoo Caper Sky Scraper, he started at 50% completion after the first session and reached 67% by his second session. However, he then plateaued until the 8th session, where he reached 83%. He remained at 83% for the last 2 weeks.

The plateaus observed for each therapy program indicates the potential need for an increase in the frequency of therapy and/or the addition of another type of therapy targeting the same auditory skill. This finding also indicates a potential flaw in the app's design, as discussed previously. For this particular participant, it is difficult to determine whether he would have reached 100% completion after 6 weeks because of the several plateaus observed. Therefore, increasing the number of therapies per week and/or adding another type of therapy may have increased the possibility of completing the therapy for each program (Bellis, 2002; Bellis & Anzalone, 2008; Chermak & Musiek, 2002; Musiek et al., 2002).

Re-Evaluation measures.

Dichotic listening. Participant 004 showed a significant weaknesses in the dichotic sounds and words subtests of the AB-DE testing pre-therapy. Additionally, he failed the DDT pre-therapy (left ear only). Post-therapy scores for the AB-DE and CU-APD were within normal limits. Participant 004's DDT score for his left ear increased from 70% (fail) to pre-therapy 85% post-therapy (pass). This finding highlights the AB-DE and the CU-APD were consistent in identifying a deficit in dichotic listening. Based on the re-evaluation measures, it appears the therapy app aided in improving dichotic listening abilities. However, there are other outside factors that could have also improved his scores.

For example, this participant's motivation and attention may have improved because he changed schools from a traditional public school to a Montessori school during the therapy program. His mother stated she observed a positive change in mood, behavior, and attention since he switched to the Montessori school. She also noted that he receives more one-on-one support and assistance in the classroom now, which has, in her opinion, aided in his learning abilities. Several studies have supported the claim that Montessori schools improve intrinsic motivation and higher levels of undivided learning, ultimately leading to higher standardized test scores for math and reading (Lillard & Else-Quest, 2006; Rathunde & Csikszentmihalyi, 2005).

Temporal processing. Participant 004's results for the AB-DE of tonal-pattern temporal processing and tonal speed were within normal limits at the pre and post-assessment. Additionally, his scores for the FPT were within normal limits pre and post-assessment. This finding indicates temporal processing was not a weakness before and after therapy. However, his first Insane Ear Plane progress score was only 10% and he did not complete the Insane Ear Plane therapy app within the 6 weeks of therapy. It should be assumed that if an individual does not have a deficit in temporal processing, he or she would be able to complete therapy within a few sessions. This highlights a mismatch between the diagnostic assessments and the therapy. For example, a person may pass the designated auditory processing skill area but still benefit from therapy or a person may fail the designated auditory processing skill area and quickly pass the therapy (Gillam et al., 2008; Thibodeau et al., 2001). This makes it even more challenging to identify who would benefit from therapy and who would not.

Case Study 5: Participant 005

Participant 005 had suspected APD according to parent report. He had a previous diagnosis of ADHD and dyslexia. His mother reported daily medication to manage his ADHD. He passed the cognitive screener (TONI-3) and language screener (CELF-4) and therefore was included in the study. This participant made progress in both therapy apps. Overall, improvements were observed mainly for the AB-DE post-therapy. Minimal improvements were observed for the CU-APD tests. A more detailed interpretation of therapy results and re-evaluation measures will be explored next.

Therapy results. Participant 005 did not reach 100% completion for either the Zoo Caper Sky Scraper or Insane Ear Plane therapy apps over the 6 week period.

However, he made consistent progress for Zoo Caper Sky Scraper. He gradually increased from 33% completion after the first session, to 83% completion at the last session (12th session). However, it was observed that he plateaued at 83% completion for sessions 5 through 12. For Insane Ear Plane, he increased gradually from 10% after the first session, to 80% completion by the 12th session.

Again, the plateau observed for Zoo Caper Sky Scraper indicates the potential need for an increase in the frequency of therapy and/or the addition of another type of therapy targeting the same the auditory skill (Bellis, 2002; Bellis & Anzalone, 2008; Chermak & Musiek, 2002; Musiek et al., 2002). It also identified a potential flaw in the app's design, as previously mentioned. For this particular participant, he may have finished the Insane Ear Plane therapy app if therapy had continued past 6 weeks. For Zoo Caper Sky Scraper, he might have made more progress if the therapy game had been altered to keep his interest and promote training (Deppeler, Taranto, & Bench, 2004). Additionally, if therapy had been administered more than twice a week, progress may have improved more steadily, and possibly to completion (Bellis 2002; Bellis & Anzalone, 2008).

Re-Evaluation measures.

Dichotic listening. Participant 005 showed mild weaknesses in the dichotic sounds and words subtests of the AB-DE testing pre-therapy. Additionally, he failed the DDT pre-therapy in the left ear only (65%). The AB-DE post-therapy assessment found normal dichotic listening skills. However, he still did not pass the DDT in the left ear (72.5%) post-therapy. Although the AB-DE identified dichotic listening abilities within normal limits, the participant's DDT scores were still outside the normal range for his age. As discussed earlier, the DDT has already been found to be both sensitive and specific (Musiek et al, 2011). These inconsistencies between tests highlight the AB-DE's potential unreliability, and have future implications for audiologists or other professionals administering this app-based therapy.

Temporal processing. Participant 005's results for the rapid tones sub-test on the AB-DE were within normal limits pre-therapy. However, he scored a significant weakness in this area post-therapy. Other tests of temporal processing were within normal limits pre and post-therapy. His scores for the FPT were outside of the normal limits for his age in both ears pre-therapy (73.33% right ear, 66.67% left ear) and post-therapy (73.33% for right and left ears). His scores for the FPT only improved for the left ear by 6.67% (one additional item correct). The AB-DE and the CU-APD tests were inconsistent in identifying this participant's auditory deficits and measuring changes following therapy. Although this participant did not make improvements to his temporal processing abilities as evident by his FPT scores and his AB-DE scores, he still made steady progress for the Insane Ear Plane therapy app. This individual finding suggests the therapy may not target the correct area of weakness as indicated by the pre and post-therapy results.

Case Study Themes

There have been several recurrent themes across therapy progress and completion, and re-evaluation results among participants. The most widely observed theme for all participants was that plateaus occur in these therapy apps. For some, this plateau was observed for the therapy app that targeted the specific area of weakness(es) identified by the CU-APD tests. This indicates the recommendations for therapy should be frequent and intense (Bellis, 2002; Bellis & Anzalone, 2008; Chermak & Musiek, 2002; Musiek et al., 2002).

Another common theme included minimal improvements to post-therapy re-evaluation scores, specifically for the CU-APD tests. This finding was observed for all participants, despite improvements observed for the AB-DE administered post-therapy. Another recurrent theme was that the AB-DE and the CU-APD tests were inconsistent in identifying the same auditory weakness, which occurred in 3 out of the 4 participants for at least one area of weakness.

The current results and themes discussed above highlight the finding that the AB-DE was unreliable in identifying areas of auditory weaknesses when compared to two tests that are sensitive and specific (Musiek et al., 2011; Musiek & Pinheiro, 1983). Additionally, the therapy apps varied widely on how they helped each participant. Some participants had zero or minimal progress, while others completed the therapy tasks quickly. As mentioned previously, these case study findings have implications for future administration of the app as a diagnostic test and/or therapy. Without a larger, intendent study, the improvements on the therapy apps or the AB-DE should be interpreted with caution, and other measures of auditory processing should be administered for accurate evaluation of auditory listening abilities.

The findings of the current study are similar to findings in other studies that examined the effects of intervention strategies on outcome measurements for children with APD (Fey et al., 2011; Deppeler et al., 2004; Miller et al., 2005; Yencer, 1998). For example, Yencer (1998) examined the effects of auditory intervention training (AIT) on the effects of auditory processing abilities in 36 participants in grades 1-4. Of the 36 participants, half were a control group and the other half were diagnosed with APD. AIT was administered for 30 minutes two times a day for 10 days total. Following therapy, the same APD measurements were administered pre-therapy to determine changes to auditory processing. The researcher discovered there were essentially no significant differences in the experimental and control participants between changes in scores pre vs. post-therapy. Although the current study did not utilize a control group, minimal differences in scores for the CU-APD test scores were observed post-therapy for some of the participants, which is similar to Yencer's (1998) findings.

Miller et al. (2005) researched several different intervention strategies for APD on seven children ages 7-9 with APD. All participants engaged in 100 minute therapy sessions five times a week for 4 weeks. Five of the participants were enrolled in a formal therapy program, and two participated in an informal auditory training program. Although they found that all participants improved somewhat in auditory measures, results for improvements were variable among participants, as some made greater improvements than others. For example, some participants improved on the staggered spondaic words (SSW) test post-therapy, but not on the SCAN-C subtests, which assesses a variety of auditory processing abilities (Miller et al., 2005). This finding indicates that the intervention strategies chosen for this study provide variable outcomes for participants. The researchers noted that the small number of participants limited the ability to generalize the findings to a larger population of individuals with APD, and accurate conclusions regarding the efficacy of the different therapy approaches were difficult to confirm. This is consistent with our findings.

Study Limitations

Accurate conclusions regarding the efficacy of this app-based therapy cannot be determined for a number of reasons. The small number of participants is a factor that severely impacts the ability to generalize these findings. Fey et al. (2011) performed a systematic review of intervention strategies for APD utilized by other researchers. Their overall conclusion was that many of the studies had very small sample sizes, and that the amount of evidence supporting these intervention strategies was too weak to determine efficacy and provide guidance for professionals administering these potential interventions.

Another observation was the need to increase the duration and frequency of treatment for anyone receiving the app-based therapy. Therapy for this study was administered twice a week for a total of 30-45 minutes, while other studies provided treatment five times a week for a total of 100 minutes per week (Deppeler et al., 2004; Miller et al., 2005). Miller et al. (2005) stated that the "dosage," or amount of time intervention should be administered to produce the best outcomes possible, is an area that needs to be better researched.

There were several participants that made zero progress or plateaued during therapy. The researchers believe that the app should be modified so that it can recognize when an individual is making little or no improvements so that it can alter how instruction are given or alter the task. Subjectively, several participants became bored with the same task given to them over and over again. This was observed by the researchers and by their parents. Deppeler, Taranto, and Bench (2004) stated that repeated testing was a limitation in their study examining APD training efficacy as well.

Many of their participants complained of boredom with the task, which led to decreased motivation and potentially impacted their performance on the task (Deppeler et al., 2004). Additionally, Miller et al. (2005) also noted that the formal auditory training programs on the computer did not hold the participants' attention as well as informal measures that were administered by the researchers. This is primarily because the informal auditory training could be altered based on the participant's motivation and attention, while the computer programs did not change or offer constructive feedback (Miller et al., 2005).

Potential Benefits for App-Based Therapy Use

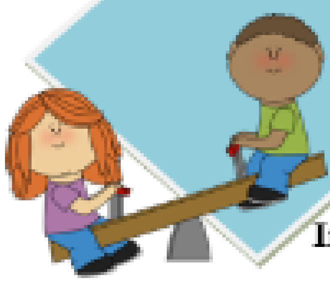
Despite the findings and limitations of the current study, app-based therapies for APD could have potential value. For example, these app-based therapies are easy to administer, as the only tools needed were an iPad and headphones. Because of the ease of administration, the individual providing therapy does not necessarily have to be a professional in the field of audiology or speech-language pathology, as the apps are designed to "run themselves" and track progress on their own. Additionally, the amount of time needed to administer therapy was very minimal, as each activity only allowed for 15 minutes per therapy session. This factor is conducive for participants with attention issues or busy schedules. Lastly, therapy could potentially continue at home without an administrator because progress can be tracked by a professional on a computer from a remote location. Of important note, the efficacy of a treatment should always be examined before generalizing treatment for individuals.

Conclusion

Overall findings from this pilot study indicate that the benefit of the app-based therapy was difficult to predict using the AB-DE or CU-APD results. Additionally, even when a participant completed or made progress with the therapy app the improvements were not consistently seen on the post-therapy CU-APD test results. Although app-based therapies could offer potential benefits in the future, findings from this study make it difficult to recommend this app for APD therapy in a clinical setting at this time. Due to limitations of the current study, a larger scale study should be conducted to more accurately determine the efficacy of this app-based therapy for the treatment of APD in children.

APPENDIX A

Participants Needed for Auditory Processing Research!



Does your child have a diagnosis of Auditory Processing Disorder (APD) and you are looking for treatment options? If so, please consider participating in this research project!

Why?

We are determining the efficacy of an app-based therapy program designed to treat APD. Treatment sessions will be conducted utilizing the Acoustic Pioneer iPad application throughout the summer. Results from testing will determine if app-based programs improve auditory processing abilities of children with an APD diagnosis.

Where?

All treatment sessions will be conducted at either the Towson University Hearing & Balance Center at the Institute for Well Being, 1 Olympic Place, Towson, MD 21204 or the Hearing and Listening Lab (HALL) in Van Bokkelen |Hall at Towson University (Dr. Smart's research laboratory). If you live more than 45 minutes from Towson University you may qualify for an alternative treatment location closer to your home (e.g., public library).

When?

Treatment will be conducted twice a week for approximately 30 minutes over a total of six weeks during the summer. Children will be rewarded with stickers and/or small toys after successful completion of each treatment session.

Who?

We are looking for male and females aged 7-12 years with a diagnosis of APD.

Interested in learning more?

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

Your child's participation is greatly appreciated!

APPENDIX B

TOWSON UNIVERSITY

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

INFORMED CONSENT FORM

Project title: The Evaluation of an App-Based Therapy Program for Auditory Processing Disorder:
A Pilot Study

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

Purpose of the Study:

Children who have difficulty with auditory processing sometimes have problems with language tasks such as following spoken instructions and understanding speech in difficult listening situations (e.g., a noisy classroom), even when they have good hearing and intelligence. Recently, application-based therapies, such as Acoustic Pioneer, have been developed to treat auditory processing disorder (APD). The purpose of this project is to determine the efficacy of the Acoustic Pioneer application in the treatment of APD.

Procedures:

If your child participates in this study, they will receive few diagnostic assessments before the therapy begins, then they'll participate in a series of therapy sessions, and after therapy they will be re-assessed to see if we can measure any changes in their listening abilities. This will involve2-3, 30 minute sessions per week for a total of six weeks. During these sessions, your child will participate in a number of different listening tasks. For some tasks your child will be asked to report back what they hear through earphones. Other tasks require your child to participate in listening games on an Apple iPad. Short breaks will be provided as needed during testing to avoid fatigue. These sessions will take place at the Hearing and Listening Lab (HALL) in Van Bokkelen Hall at Towson University (Dr. Smart's research laboratory) or at the Hearing and Balance Clinic at the Institute for Well Being. Children usually enjoy the variety of listening games and activities so we anticipate that they will be excited about this study. But if, at any time, your child decides he/she does not want to participate the testing or therapy will cease immediately.

Risks/Discomfort:

There are no known risks for participating in this study.

Benefits:

A hearing screening and some diagnostic APD testing will be performed at no cost to you. Therapy for APD is also provided no cost. The data collected during this research study will be used to determine the efficacy of application-based therapy programs for the treatment of APD.

Participation:

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

Compensation:

No compensation will be provided. Your child will receive a small prize at the end of the therapy to reward him/her for their hard work.

Confidentiality:

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

Please indicate whether or not you wish to have your child participate in this project, by checking a statement below.

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

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

______ Affirmative agreement of child

____ _______________
Parent/Guardian's signature Date

Home address: ____

____

____

Home phone number: _______________________________________

Email address: ____

______________________________________ _______________
Principal Investigator’s Signature Date

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

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

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

INFORMED ASSENT FORM

Project title: The Evaluation of an App-Based Therapy Program for Auditory Processing Disorder

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

Information Sheet for Participants

(To be read aloud to each participant)

Purpose of study

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

What tests does the study involve?

First of all, we will complete activities like repeating back numbers you hear through headphones, or listening to different patterns of beeps.

We will also play a series of listening games using an iPad. These games will involve listening to animal sounds or whistles. You will then have to touch the screen to determine where the sound was coming from, or identify a pattern of sounds. All of the sounds will be presented at a comfortable volume through a set of headphones.

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

Visits

You will come to see us two times a week for six weeks at Towson University. Due to distance, if you are unable to complete the therapy sessions at Towson University, it can be performed at a quiet location closer to your home (i.e. a public library). Each visit will last about 30 minutes.

Child Assent Form

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

Title of Project: The Evaluation of an App-Based Therapy Program for Auditory Processing Disorders

Primary Investigators: Jennifer Smart, Ph.D. and Stephanie Nagle, Ph.D.

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

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

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

……………….…………………………………… ………………………………………….

Child's Name Researcher's Signature

Today's date:…………………………………

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

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

APPENDIX C

TOWSON UNIVERSITY

September 3, 2015

To: Jennifer Smart
Department of Audiology, Speech-Language Pathology and Deaf Studies
Modifications to TU IRB project 15-A084

Office of Sponsored Programs & Research
Towson University
8000 York Road
Towson, MD 21252-0001
t. 410 704-2236
f. 410 704-4494
www.towson.edu/ospr

Dr. Smart,

Thank you for informing the Towson IRB of your modifications to project 15-A084 "The Evaluation of an App-Based Therapy Program for Auditory Processing Disorder: A Pilot Study".

The Towson University Institutional Review Board for the Protection of Human Participants has reviewed and approved your modification for this project. However, this modification approval does not change the expiration date of the original approval, which will need to be renewed one year from the date of approval if the research is ongoing.

If any other modifications are made to this project, or if any new risks are discovered, please inform the Board immediately.

Should you have any questions, please do not hesitate to contact me at 410-704-2236.

Sincerely,

V. Denise Spears, MPA
Compliance Administrator, On Behalf of Towson University Institutional Review Board for the Protection of Human Participants

CC:
File

APPENDIX D

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

CHILD CASE HISTORY FORM

Child's Name:____

Date of birth:Age: _________

Home Address: ____
______

Home phone: ______________________Parent Work or Cell phone:
____

Parent/Guardian names:____

School& Teacher:__________________________________Current Grade: _________

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

____

I. BIRTH HISTORY

Pregnancy and Delivery:

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

*If yes, please explain:

____

____

____

____

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

____

____

3. Delivery by Caesarian? Yes _____ No _____

Neonatal Period (check where appropriate):

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

*If yes, please explain:

____

____

____

____

What was the birth weight? _____lbs. ____oz

Were there any feeding problems? Yes _____ No _____

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

II. DEVELOPMENTAL HISTORY

Development:

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

   If yes, which instrument? ____________________________________

III. MEDICAL HISTORY

A. Major Childhood Illnesses:

	Age
1. Mumps	____
2. Measles	____
3. Chicken Pox	____
4. Seizures	____

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

If yes, please explain:____

____

B. Other diagnoses:

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

Hearing loss: Yes____ No ____ comments:___________________________________

Dyslexia: Yes ____No ____ comments:___________________________________

Reading disorder: Yes ____No ____
comments:___________________________________

Learning disability: Yes ____No ____
comments:___________________________________

ADD/ADHD: Yes ____No ____ comments:___________________________________

Language Disorder: Yes ____No ____
comments:___________________________________

Autism Spectrum Disorder: Yes ____No ____
comments:______________________________

Asperger Syndrome: Yes ____No ____
comments:___________________________________

Anxiety Disorder: Yes ____No ____
comments:___________________________________

Other:_________________

IV. OTOLOGICAL HISTORY

	Yes	No	How many?	Which ear(s)?	Age(s)
Ear infections:	____	____	__________	__________	
Ears draining:	____	____	__________	___________	
Chronic colds:	____	____	__________	___________	

Has the child had the following:

	Yes	No	Age(s)
Pressure Equalization (P.E.) Tubes?	____	____	______

If yes, which ear(s): ____?

Tonsillectomy? _____ _____ ______

Adenoidectomy? _____ _____ ______

V. AUDITORY PROCESSING DISORDER

A. Diagnosis: Yes_______ No________

a. If yes:

i. Date of Diagnosis:_____________________

ii. Professional who gave diagnosis: ___________________

iii. Therapy: Yes_________ No_________

1. If yes, explain:

____

____

B. Suspected: Yes________ No_________

IV. Treatment or Therapies?

Has your child received treatment or therapy services for their APD? *Check all that apply*:

1. Aural Rehabilitation _____

   Briefly describe:____

2. Auditory Training _____

   Briefly describe:____

3. FM system ____

   Briefly describe:____

4. Language Therapy with a Speech-Language Pathologist

   Briefly describe:____

5. Other

Briefly describe:____

How did you learn about our study?

____

____

APPENDIX E

TOWSON UNIVERSITY

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

Date:______________________________

Dear Parent/Guardian(s)of: ____

Below is a description of each therapy activity and APD assessments utilized in the current study, *The Evaluation of an App-Based Therapy Program for Auditory Processing Disorder: A Pilot Study*, followed by a table with the summary of the results. A summary of the results are found below.

<u>Assessment</u>:

Dichotic Listening Assessment Tasks

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

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

Temporal Processing and Patterning Tasks

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

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

The Acoustic Pioneer App's diagnostic test battery:

This app based assessment includes a variety of listening activities involving several auditory processes. However, the most commonly assessed auditory processing areas include dichotic listening and temporal processing which are described above. Acoustic Pioneer also includes low redundancy tasks which are tests that simulate challenging listening environments like listening in background noise. Listed below are the areas assessed in the app-based diagnostic battery:

- Hearing Screening and Lateralization
- Tonal-Pattern Temporal Processing
- Tonal-Pattern Memory
- Rapid Tones
- Dichotic Tones
- Global Tone Score
- Word Memory
- Rapid Speech
- Dichotic Words
- Combined Dichotic Score
- Speech-in-Noise (without localization cues)
- Speech-in-Noise (with localization cues)

<u>Therapy Activities</u>

Zoo Caper Sky Scraper

This therapy activity was an app-based game played on an Apple iPad. It was designed for children who have deficits in dichotic listening skills. Games involving the presentation of dichotic stimuli were introduced with increasing difficulty. Several animal sounds were played in the child's ears, and the child had to determine which animals made those sounds.

Insane Ear-Plane

This therapy activity was an app-based game played on an Apple iPad. It was designed for children who have deficits with processing sounds in a time domain. Different activities were administered to improve tonal memory, differentiating similar pitches, and tonal-patterning.

Summary of Routine APD Assessment Test Results Before and After Therapy

Test- *Before* Therapy	**Interpretation**	**Scores**	**Normative Scores**
Tests			
Dichotic Double Digits	Pass:_______________ Fail:_______________	Right Ear- Left Ear-	
Frequency Pattern Sequence	Pass:_______________ Fail:_______________	Right Ear- Left Ear-	

Test- *After* Therapy	**Interpretation**	**Scores**	**Normative Scores**
Tests			
Dichotic Double Digits	Pass:_______________ Fail:_______________	Right Ear- Left Ear-	
Frequency Pattern Sequence	Pass:_______________ Fail:_______________	Right Ear- Left Ear-	

Summary of Acoustic Pioneer Diagnostic Test Results Before and After Therapy:

Test-Before Therapy	**Interpretation**
Hearing Screening and Lateralization	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Tonal-Pattern Temporal Processing	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Tonal-Pattern Memory	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Rapid Tones	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Dichotic Tones	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________

Global Tone Score	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Word Memory	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Rapid Speech	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Dichotic Words	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Combined Dichotic Score	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Speech-in-Noise (without localization cues)	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Speech-in-Noise (with localization cues	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________

Test-After Therapy	**Interpretation**
Hearing Screening and Lateralization	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Tonal-Pattern Temporal Processing	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Tonal-Pattern Memory	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Rapid Tones	Normal Result: ____________________ Mild Weakness: ___________________ Severe Weakness: __________________
Dichotic Tones	Normal Result: ____________________

	Mild Weakness: __________________ Severe Weakness: _________________
Global Tone Score	Normal Result: ___________________ Mild Weakness: __________________ Severe Weakness: _________________
Word Memory	Normal Result: ___________________ Mild Weakness: __________________ Severe Weakness: _________________
Rapid Speech	Normal Result: ___________________ Mild Weakness: __________________ Severe Weakness: _________________
Dichotic Words	Normal Result: ___________________ Mild Weakness: __________________ Severe Weakness: _________________
Combined Dichotic Score	Normal Result: ___________________ Mild Weakness: __________________ Severe Weakness: _________________
Speech-in-Noise (without localization cues)	Normal Result: ___________________ Mild Weakness: __________________ Severe Weakness: _________________
Speech-in-Noise (with localization cues	Normal Result: ___________________ Mild Weakness: __________________ Severe Weakness: _________________

Results from this research study suggest that your child should:

- Continue therapy for APD with a Speech-Language Pathologist or Audiologist _________
- Received additional treatments for APD such as ______________________________
- Seen by a(n) ____________________________________ for additional testing __________
- No further testing is needed at this time ___________

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

______________________________ ______________________________

Hanna Moses, B.S.
Co-Investigator

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

APPENDIX F

Pre and Post-Therapy Test Scores for each subtest of the App-Based Diagnostic Evaluation for each Participant

	Participant 1		Participant 2		Participant 3		Participant 4		Participant 5	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
Hearing Screening/Lateralization	Significant Weakness	Mild Weakness	Normal Result	Normal Result	N/A	N/A	Normal Result	Normal Result	Normal Result	Normal Result
Tonal-Pattern Temporal Processing	Normal Result	Normal Result	Normal Result	Normal Result	N/A	N/A	Normal Result	Normal Result	Normal Result	Normal Result
Tonal-Pattern Memory	Normal Result	Normal Result	Normal Result	Significant Weakness	N/A	N/A	Normal Result	Normal Result	Significant Weakness	Normal Result
Rapid Tones	Normal Result	Normal Result	Normal Result	Normal Result	N/A	N/A	Normal Result	Normal Result	Normal Result	Significant Weakness
DD sounds	Significant Weakness	Normal Result	Mild Weakness	Normal Result	Significant Weakness	Normal Result	Significant Weakness	Normal Result	Mild Weakness	Normal Result
Word Memory	Significant Weakness	Normal Result	Normal Result	Normal Result	Normal Result	Significant Weakness	Mild Weakness	Normal Result	Normal Result	Normal Result
Rapid Speech	Significant Weakness	Normal Result	Normal Result	Significant Weakness	Normal Result	Normal Result	Normal Result	Normal Result	Significant Weakness	Mild Weakness
DD Words	Significant Weakness	Normal Result	Significant Weakness	Normal Result	Significant Weakness	Normal Result	Significant Weakness	Normal Result	Mild Weakness	Normal Result
SPIN (w/o localization cues)	Normal Result	Normal Result	Normal Result	Normal Result	Normal Result	Normal Result	Normal Result	Normal Result	Mild Weakness	Mild Weakness
SPIN (w/ localization cues)	Normal Result	Normal Result	Normal Result	Normal Result	Normal Result	Normal Result	Normal Result	Normal Result	Normal Result	Normal Result

References

American Academy of Audiology. (2010). *Clinical Practice Guidelines: Diagnosis, Treatment and Management of Children and Adults with Central Auditory Processing Disorder.* Reston, VA: American Academy of Audiology. http://www.audiology.org/resources/documentlibrary/Documents/CAPD%20Guidelines%208-2010.pdf.

American Speech-Language-Hearing Association.(2005). (Central) auditory processing disorders [Technical report]. Available from www.asha.org/policy.

Bamiou, D. E., Campbell, N., & Sirimanna, T. (2006). Management of auditory processing disorders. *Audiological Medicine, 4*, 46-56.

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

Bao, S., Chang, E. F., Woods, J., & Merzenich, M. M. (2004). Temporal plasticity in the primary auditory cortex induced by operant perceptual learning. *Nature Neuroscience*, *7*(9), 974-981.

Baran, J. A., Shinn, J. B., & Musiek, F. E. (2006). New development in the assessment and management of auditory processing disorders. *Audiological Medicine, 4,* 35-45.

Barker, M. D., & Purdy, S. C. (2015). An initial investigation into the validity of a computer-based auditory processing assessment (Feather Squadron). *International Journal of Audiology, 55*(3), 173-183.

Bellis, T. J. (2002). Developing deficit-specific intervention plans for individuals with auditory processing disorders. *Seminars in Hearing, 23*(4), 287-295.

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

Bellis, T. J., & Anzalone, A. M. (2008). Intervention approaches for individuals with (central) auditory processing disorder. *Contemporary Issues in Communication Science and Disorders, 35*, 143-153.

Bellis, T. J., Nicol, T., & Kraus, N. (2000). Aging affects hemispheric asymmetry in the neural representation of speech sounds. *Journal of Neuroscience, 20*(2), 246-263.

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

Berlin, C. I. Hood, L., Morlet, T., Rose, K., & Brashears, S. (2003). Auditory neuropathy/dys-synchrony: Diagnosis and management. *Mental Retardation and Developmental Disabilities Research Reviews*, *9*, 225-231.

Berlin, C. I., Lowe-Bell, S. S., Cullen, J. K., Thompson, C. L., & Loovis, C. F. (1973). Dichotic speech perception: An interpretation of right-ear advantage and temporal offset effects. *The Journal of the Acoustical Society of America, 53*(3), 699-709.

Bornstein, S., Wilson, R., & Cambron, N. (1994). Low- and high-pass filtered Northwestern University Auditory Test No. 6 for monaural and binaural evaluation. *Journal of the American Academy of Audiology, 5*(4), 259-264.

Breier, J. I., Fletcher, J. M., Foorman, B. R., Klaas, P., & Gray, L. C. (2003). Auditory temporal processing in children with specific reading disability with and without attention deficit/hyperactivity disorder. *Journal of Speech, Language, and Hearing Research, 46*(1), 31-42.

Cameron, S., & Dillon, H. (2007). Development of the listening in spatialized noise-sentences test (LISN-S). *Ear & Hearing*, *28*(2), 196-211.

Cameron, S., Dillon, H., Brown, D., Keith, R., Martin, J., & Watson, C. (2009). Development of the North American listening in spatialized noise-sentences test (NA LiSN-S): Sentence equivalence, normative data, and test-retest reliability studies. *Journal of the American Academy of Audiology*, *20*(2), 128-146.

Chermak, G. D. (1998). Managing central auditory processing disorders. *Seminars in Hearing, 19*(4), 379-392.

Chermak, G. D. (2002). Deciphering auditory processing disorders in children. *Otolaryngology Clinics of North America, 35*, 733-749.

Chermak, G. D., Hall, J. W., & Musiek, F. E. (1991). Differential diagnosis and management of central auditory processing disorder and attention deficit hyperactivity disorder. *Journal of the American Academy of Audiologists, 10*, 239-303.

Chermak, G. D., & Musiek, F. E. (2002). Auditory training: Principles and approaches for remediating and managing auditory processing disorders. *Seminars in Hearing, 22*(4), 297-308.

Chermak, G. D., Somers, E. K., & Seikel, J. A. (1998). Behavioral signs of central auditory processing disorder and attention deficit hyperactivity disorder. *Journal of the American Academy of Audiology, 9*, 78-84.

Dahmen, J. C., & King, A. J. (2007). Learning to hear: Plasticity of auditory cortical processing. *Current Opinion in Neurobiology, 17,* 456-464.

Dayal, V. S., Tarantino, L., & Swisher, L. P. (1966). Neurootologic studies in multiple sclerosis. *Laryngoscope, 76*, 1798.

DeBonis, D. A., & Moncrieff, D. (2008). Auditory processing disorders: An update for speech-language pathologists. *American Journal of Speech-Language Pathology, 17,* 4-18.

Deppeler, J. M., Taranto, A. M., & Bench, J. (2004). Language and auditory processing changes following Fast ForWord. *Australian and New Zealand Journal of Audiology, 26*(2), 94–109.

Dias, K. Z., Jutras, B., Acrani, I. O., & Pereira, L. D. (2012). Random Gap Detection Test (RGDT) performance of individuals with central auditory processing disorders from 5 to 25 years of age. *International Journal of Pediatric Otorhinolaryngology, 76,* 174-178.

Dobrzanski-Palfrey, T., & Duff, D. (2007). Central auditory processing disorders: Review and case study. *Axon, 28*(3), 20-23.

Emanuel, D. C., Ficca, K. N., & Korczak, P. (2011). Survey of the diagnosis and management of auditory processing disorder. *American Journal of Audiology, 20*(1), 48-60.

Emanuel, D. C., Smart, J. L., Bernhard, S., & McDermott, E. (2013, July-August). What's up with the C? *Audiology Today*, 24-29.

Fey, M. E., Richard, G. J., Geffner, D., Kamhi, A.G., Medwetsky, L., Paul, D., … Schooling, T. (2011). Auditory processing disorder and auditory/language interventions: An evidence-based systematic review. *Language, Speech, and Hearing Services in Schools, 42*(3), 246-264.

Fifer, R. C., Jerger, J. F., Berlin, C. I., Tobey, E. A., & Campbell, J. C. (1983). Development of a dichotic sentence identification test for hearing-impaired adults. *Ear & Hearing, 4*, 300-305.

Foli, K. J., & Elsisy, H. (2009). Influence, education, and advocacy: The pediatric nurse's role in the evaluation and management of children with central auditory processing disorders. *Journal for Specialists in Pediatric Nursing, 15*(1), 62-71.

Friel-Patti, S. (1999). Clinical decision-making in the assessment and intervention of central auditory processing disorders. *Language, Speech, & Hearing Services in Schools, 30*(4), 345-352.

Geers, A. E. (2002). Factors affecting the development of speech, language, and literacy in children with early cochlear implantation. *Language, Speech, and Hearing Services in Schools, 33*, 172-183.

Gold, J. I., & Knudsen, E. I. (2000). Abnormal auditory experience induces frequency-specific adjustments in unit tuning for binaural localization cues in the optic tectum of juvenile owls. *The Journal of Neuroscience, 20*(2), 862-877.

Golding, M., Carter, N., Mitchell, P., & Hood, L. J. (2004). Prevalence of central auditory processing (CAP) abnormality in an older australian population: The blue mountains hearing study. *Journal of the American Academy of Audiology, 15*, 633-642.

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

Grutzendler, J., Kasthuri, N., & Gan, W. (2002). Long-term dendritic spine stability in the adult cortex. *Nature, 420*, 812-816.

Hällgren, M., Johansson, M., Larsby, B., & Arlinger, S. (1998). Dichotic speech tests. *Scandinavian Audiology, 27*(49), 35-39.

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

Hind, S. E., Haines-Bazrafshan, R., Benton, C. L., Brassington, W., Towle, B., & Moore, D. R. (2011). Prevalence of clinical referrals having hearing thresholds within normal limits. *International Journal of Audiology, 50*(10), 708-716.

Hurley, A., & Musiek, F. E. (1997). Effectiveness of three central auditory processing (CAP) tests in identifying cerebral lesions. *Journal of the American Academy of Audiology, 8*(4), 257-262.

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

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

Karlsson, A. K., & Rosenhall, U. (1995). Clinical application of distorted speech audiometry. *Scandinavian Audiology, 24*(3), 155-160.

Keith, R. (1986). SCAN: A Screening Test for Auditory Processing Disorders. San Diego, CA: The Psychological Corporation.

Keith, R. W. (1999). Clinical issues in central auditory processing disorders. *Language, Speech, and Hearing Services in Schools, 30*, 339-344.

Keith, R. W., & Engineer, P. (1991). Effects of methylphenidate on the auditory processing abilities of children with attention deficit-hyperactivity disorder. *Journal of Learning Disabilities, 24*(10), 630-636.

Keller, W. D., Tillery, K. L., & McFadden, S. L. (2006). Auditory processing disorder in children diagnosed with nonverbal learning disability. *Research and Technology, 15*, 108-113.

Kennedy, V., Wilson, C. & Stephens, D. (2006). When a normal hearing test is just the beginning. *Journal of the Royal Society of Medicine, 99*, 417 – 420.

Kimura, D. (1961). Some effects of temporal-lobe damage on auditory perception. *Canadian Journal of Psychology, 15*(3), 156-165.

Kral, A., & Sharma, A. (2012).Developmental neuroplasticity after cochlear implantation. *Trends in Neurosciences*, *35*(2), 111-122.

Kumar, U. A., & Jayaram, M. M. (2006). Prevalence and audiological characteristics in individuals with auditory neuropathy/auditory dys-synchrony. *International Journal of Audiology, 45*, 360-366.

Lillard, A., & Else-Quest, N. (2006). Evaluating montessori education. *Science*, 311 (5795), 1893 – 1894.

McDermott, E. E., Smart, J. L., Boiano, J. A., Bragg, L. E., Colon, T. E., Hanson, E. M., … Kelly, A. S. (2016). Assessing auditory processing abilities in typically developing school-aged children. *Journal of the American Academy of Audiology, 27*, 72-84.

Merzenich, M. M., Jenkins, W. M., Johnston, P., Schreiner, C., Miller, S. L., & Tallal, P. (1996). Temporal processing deficits of language-learning impaired children ameliorated by training. *Science*, *271*, 77-81.

Miller, C. A. (2011). Auditory processing theories of language disorders: Past, present, and future. *Language, Speech, and Hearing Services in Schools*, *42*, 309-319.

Miller, C. A., Uhring, E. A., Brown, J. J. C., Kowalski, E. M., Roberts, B., & Schaefer, B. A. (2005). Case studies of auditory training for children with auditory processing difficulties: A preliminary analysis. *Contemporary Issues in Communication Science & Disorders, 32*, 93–107.

Moncrieff, D. W. (2011). Dichotic listening in children: Age-related changes in direction and magnitude of ear advantage. *Brain and Cognition, 76*, 316-322.

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

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

Moore, D. R. (2011). The diagnosis and management of auditory processing disorder. *Language, Speech, and Hearing Services in Schools, 42*, 303-308.

Moossavi, A., Mehrkian, S., Lotfi, Y., Faghihzadeh, S., & Sajedi, H. (2014). The relation between working memory capacity and auditory lateralization in children with auditory processing disorders. *International Journal of Pediatric Otorhinolaryngology, 78*(11), 981-1986.

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

Musiek, F. E., (1994). Frequency (pitch) and duration pattern tests. *Journal of the American Academy of Audiology*, *5*, 265-268.

Musiek. F. E. (1999a). Central Auditory Tests. *Scandinavian Journal of Audiology, 51*, 33-46.

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

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

Musiek, F.E., & Chermak, G.D. (2007). *Handbook of (central) auditory processing disorder.* San Diego, CA: Plural Publishing Inc.

Musiek, F. E., Chermak, G. D., Weihing, J., Zappulla, M., & Nagle, S. (2011). Diagnostic accuracy of established central auditory processing test batteries in patients with documented brain lesions. *Journal of the American Academy of Audiology, 22*, 342-358.

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

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

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

Musiek, F. E., Shinn, J., & Hare, C. (2002).Plasticity, auditory training, and auditory processing disorders. *Seminars in Hearing*, *23*(4), 263-276.

Musiek, F., Shinn, J., Jirsa, R., Bamiou, D., Baran, J., & Zaida, F. (2005). GIN (gaps-in-noise) test performance in subjects with confirmed central auditory nervous system involvement. *Ear & Hearing, 26*(6), 608-618.

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

Norrix, L. W., & Velenovsky, D. S. (2014). Auditory neuropathy spectrum disorder: A review. *Journal f Speech, Language & Hearing Research,57*(4), 1564-1576.

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

Plack, C., & Viemeister, N. (1993). Suppression and the dynamic range of hearing. *The Journal of the Acoustical Society of America, 36*, 976-982.

Plenge, G. (1974). On the differences between localization and lateralization. *The Journal of the Acoustical Society of America, 56*(3), 944-951.

Polley, D. B., Steinberg, E. E., Merzenich, M. M. (2006). Perceptual learning directs auditory cortical map reorganization through topdown influences. *Journal of Neuroscience, 26*, 4970-4982.

Putter-Katz, H., Said, L. B., Feldman, I., Miran, D., Kushnir, D., Muchnik, C., & Hildesheimer, M. (2002). Treatment and evaluation indices of auditory processing disorders. *Seminars in Hearing, 23*(4), 357-364.

Rosen, S., Cohen, M., & Vanniasegaram, I. (2010). Auditory and cognitive abilities of children suspected of auditory processing disorder (APD). *International Journal of Pediatric Otorhinolaryngology, 74*, 594-600.

Rathunde, K., & Csikszentmihalyi, M. (2005). Middle school students’ motivation and quality of experience: A comparison of Montessori and traditional school environments. *American Journal of Education, 111*(3), 341-371.

Ryan, A., & Logue-Kennedy, M. (2013). Exploration of teachers' awareness and knowledge of (central) auditory processing disorder ((C)APD). *NASEN*, *40*(4), 167-174.

Sharma, M., Purdy, S., & Kelly, A. S. (2009).Comorbidity of auditory processing, language, and reading disorders. *Journal of Speech, Language, and Hearing Research, 52*, 706-722.

Sharma, M., Purdy, S. C., & Kelly, A. S. (2012). A randomized control trial of interventions in school-aged children with auditory processing disorders. *International Journal of Audiology, 51*(7), 506-518.

Sinah, O. (1959). The role of the temporal lobe in hearing. Thesis, McGill University, Montreal, Canada.

Thibodeau, L., Friel-Patti, S., & Britt, L. (2001). Psychoacoustic performance in children completing Fast ForWord training. *American Journal of Speech-Language Pathology, 10*(3), 248-257

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

Zhang, L. I., Bao, S., & Merzenich, M. M. (2001). Persistent and specific influences of early acoustic environments on primary auditory cortex. *Neuroscience*, *4*(11), 1123-1130.

CURRICULUM VITA

Hanna T. Moses
17 Ruxview Court, Apt. 301
Towson, MD 21204

Educational History:

Clinical Doctorate in Audiology Towson University, Towson, MD
Expected Graduation Date: May 2017 Current GPA: 3.99/4.00
Research in progress: The Evaluation of an App-Based Therapy Program for Auditory Processing Disorder: A Pilot Study

Bachelor of Science Towson University, Towson, MD
August 2009-May 2013 Overall GPA: 3.96
Graduated Summa Cum Laude

Clinical Experience

Greater Baltimore Medical Center/ENT Associates: Baltimore, MD
Graduate Clinician (1/2016 to 5/2016)
Supervisor: Kimberly Bank, Au.D., CCC-A

The Maryland School for the Deaf: Frederick, MD
Graduate Clinician (8/2015 to 12/2015)
Supervisor: Michelle Bode, Au.D., CCC-A

ENTAA Care: Annapolis, MD
Graduate Clinician (6/2015 to 8/2015)
Supervisor: Stephen Pallett, Au.D., CCC-A

The Pennsylvania State Milton S. Hershey Medical Center: Hershey, PA
Graduate Clinician (1/2015 to 5/2015)
Supervisor: Beth Czarnecki, Au.D., CCC-A

Towson University Hearing & Balance Clinic: Towson, MD
Graduate Clinician (1/2014 to 12/2014)
Supervisor: various

Professional Memberships

Student Academy of Audiology (SAA)
Student Member (August 2013-present)
Director of Archives Towson University Chapter (June 2014 to May 2015)
National Student Speech Language Hearing Association (NSSLHA)
Student Member (September 2015-present)