TOWSON UNIVERSITY
COLLEGE OF GRADUATE STUDIES AND RESEARCH

AN INVESTIGATION OF THE INFLUENCE OF GENDER ON AUDITORY PROCESSING ABILITIES IN TYPICALLY DEVELOPING CHILDREN

by

Julie Boiano

A Thesis

Presented to the faculty of

Towson University

in partial fulfillment

of the requirements for the degree

Doctor of Audiology

May 2013

Towson University
Towson, Maryland 21252

TOWSON UNIVERSITY
OFFICE OF GRADUATE STUDIES

THESIS APPROVAL PAGE

This is to certify that the thesis prepared by Julie Boiano, B.S., Au.D. Candidate entitled An Investigation of the Influence of Gender on Auditory Processing Abilities in Typically Developing Children 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.
Chair, Thesis Committee — Date: 5/7/12

Diana C. Emanuel, Ph.D.
Committee Member — Date: 05/07/12

Andrea Kelley, Ph.D.
Committee Member — Date: 8/5/12

Janet Delany, D.Ed.
Dean of Graduate Studies — Date: May 15, 2012

ACKNOWLEDGEMENTS

I would like to thank several people for their continual support, motivation, and guidance over the past year and a half. First and foremost, I would like to thank Dr. Smart, my thesis advisor, for the countless hours she spent advising me, reviewing my written work, and answering my seemingly endless questions. I appreciate all of your assistance and moral support throughout this entire process and am grateful to have had such a dedicated thesis committee chair member. Next, I would like to thank my other thesis committee members, Dr. Emanuel and Dr. Kelly, for supporting my thesis project and for their assistance with the development of the testing protocol and reviews of my manuscript. I would also like to thank Dr. Daniel Agley for his assistance with the statistical analyses and results portion of my project. Additionally, I want to recognize my thesis partner, Tiffany Colon, for the endless hours, days, weeks, and months we have spent together researching, writing, testing, and presenting our thesis project. Lastly, I would sincerely like to thank my parents, family members, classmates, and closest friends for their unwavering support throughout the entire thesis process. Without all of your encouragement and motivation throughout the years, I could not have made it through this project, both mentally and physically, and for that I cannot thank you enough!

ABSTRACT

An Investigation of the Influence of Gender on Auditory Processing Abilities in Typically Developing Children

Julie Boiano

The auditory processing abilities of 27 typically developing children between the ages of 7;0 and 12;11 years were assessed using a behavioral auditory processing test battery and an additional test battery in order to develop age-appropriate normative data for the local population. All participants were screened using an additional test battery to evaluate their nonverbal IQ, phonological processing, and sustained attention abilities. The participants were age and gender balanced in order to investigate the potential influence of maturation and gender on auditory processing abilities. Results revealed an overall improvement in auditory processing abilities with increasing age for some assessments, primarily between the youngest and oldest age groups (i.e., 7-8 year group and 11-12 year group). Although the significant influence of age was not observed on all tests, it is important to recognize the presence of elevated test performance and ceiling effects for most auditory processing assessments. Further, results revealed that the auditory processing abilities of males and females were not statistically different, nor was there a significant difference between left and right ear performance. This study represents one-fourth of a larger scale research study and, ultimately, the results will be collapsed across studies and normative data developed for the region.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

KEY TO ABBREVIATIONS

AAA: American Academy of Audiology
ADHD: Attention-Deficit Hyperactivity Disorder
AFG: Auditory Figure Ground
ANOVA: Analysis of Variance
APD: Auditory Processing Disorder
ANSI: American National Standards Institute
ART: Acoustic Reflex Threshold
ASHA: American Speech-Language Hearing Association
CANS: Central Auditory Nervous System
CAPD: Central Auditory Processing Disorder
CELF-4: Clinical Evaluation of Language Fundamentals (4^{th} Edition)
CID-W22: Central Institute for the Deaf-Words
CNS: Central Nervous System
CRW Test: Compressed & Reverberated Words Test
CTOPP: Comprehensive Test of Phonological Processing
dB: Decibel
DDT: Dichotic Digits Test
DPT: Duration Pattern Test
DSI: Dichotic Sentence Identification
DSM-IV: Diagnostic and Statistical Manual of Mental Disorders (4^{th} Edition)
FPT: Frequency Pattern Test
GIN Test: Gaps in Noise Test
GSI: Grason-Stadler Instrument
HL: Hearing Level
IAC: Industrial Acoustics Company
IQ: Intelligence Quotient
IRB: Institutional Review Board
IVA-CPT: Integrated Visual and Auditory-Continuous Performance Test
LEA: Left Ear Advantage
LiSN Test: Listening in Spatialized Noise Test
LiSN-S Test: Listening in Spatialized Noise-Sentences Test
NEA: No Ear Advantage
P.E.: Pressure Equalization
RDDT: Randomized Dichotic Digits Test
REA: Right Ear Advantage
RGDT: Random Gap Detection Test
SES: Socio-Economic Status
SLI: Specific Language Impairment
SNR: Signal-to-Noise Ratio

SRT: Speech Reception Threshold
SSW: Staggered Spondaic Words Test
TEOAE: Transient Evoked Otoacoustic Emission
TONI-3: Test of Nonverbal Intelligence (3rd Edition)
TU-SLHC: Towson University Speech, Language & Hearing Center
VA: Veterans Administration
WRS: Word Recognition Score

CHAPTER 1

Introduction

Auditory processing disorder (APD) can be defined simply as the inefficient or ineffective processing of auditory stimuli that cannot be explained by a peripheral hearing loss (American Speech, Language, & Hearing Association [ASHA], 2005; Jerger & Musiek, 2000; Witton, 2010). Auditory processing disorder is characterized by persistent listening difficulties that can be complicated by adverse environments (Jerger & Musiek, 2000). Prevalence estimates indicate that approximately 2-3% of school aged children are affected by APD (Chermak & Musiek, 1997). Those identified with APD may experience difficulty in a range of areas, including but not limited to understanding in the presence of background noise, following directions, localizing sound, and/or understanding rapid speech (American Academy of Audiology [AAA], 2010; Jerger & Musiek, 2000). These areas of difficulty or weakness may adversely affect a child's performance in the classroom and hinder his or her ability to learn efficiently and effectively.

Due to the complex nature of the brain, it is likely for weaknesses in one area to influence more than one behavior (Witton, 2010). This has important implications for the assessment, diagnosis, and management of individuals with APD, as it is likely to co-occur with several other behavioral disorders. Reading disorders, language disorders, and attention-deficit hyperactivity disorder are among the most commonly co-occurring conditions in those with APD (Bamiou, Musiek & Luxon, 2001; Chermak, Hall, & Musiek, 1999; Sharma, Purdy & Kelly, 2009). A study by Sharma et al. (2009) highlighted the comorbid nature of APD, indicating that of 72% of the 68 children in the study who were diagnosed with APD (n=49), only 4% were considered to be purely APD (n=3).

In order to accurately assess the presence of APD, it is necessary to examine the prevalence of this disorder and identify any biases that may exist. Numerous brain based disorders exhibit an asymmetry between genders, and evidence has shown that many of these conditions are more commonly displayed by males. Autism, ADHD, and reading and language impairments all display prevalence estimates that are asymmetrical between genders, and present more often in boys than girls (Bauermeister et al., 2007; Flax, Realpe-Bonilla, Brzustowicz, Bartlett, & Tallal, 2003; Yeargin-Allsop et al., 2003). Certain tasks of dichotic listening abilities have also displayed consistently different findings between genders (Bellis & Wilber, 2001; Jerger, Chmiel, Allen, & Wilson, 1994). There has been speculation as to if a similar gender bias exists within other areas of APD.

An accurate diagnosis of APD relies on the administration of a comprehensive test battery composed of sensitive and specific tests that assess a variety of auditory processing skills (AAA, 2010; ASHA, 2005). An in-depth case history, evaluation of peripheral auditory sensitivity, and any necessary assessments, including those of language, phonological processing, nonverbal IQ, and sustained attention, should be administered (by other professionals, if necessary) prior to an auditory processing evaluation (ASHA, 2005). Although there is no "gold standard" APD test battery, tasks of dichotic listening, monaural low redundancy, and temporal processing are major areas that should typically be included in an audiologist's core test battery (AAA, 2010; ASHA, 2005). Interpretation of most tests within an APD assessment requires comparisons to appropriate, well-established normative data. Auditory processing abilities typically progress and develop as maturation of the auditory nervous system evolves, further supporting the need for well-established normative data across age groups (Bamiou et al., 2001; Chermak & Musiek, 1997). As such, with age comes an increased ability to complete complex tasks of auditory processing (Moore, Ferguson, Edmondson-Jones, Ratib, & Riley, 2010). These changes should be considered in conjunction with gender status, as the gender differences seen in other developmental disorders support the investigation of the effect on auditory processing abilities.

CHAPTER 2

Review of the Literature

Auditory Processing Disorder

The auditory system is composed of a complex set of pathways through the peripheral and central nervous systems, which link individuals to the sounds and stimuli surrounding them. When a problem inhibits proper sound transmission through this system, the listener may misperceive a signal. One such example of inefficient sound processing is known as auditory processing disorder (or APD) (AAA, 2010; ASHA, 2005). Numerous neurologic etiologies can alter the extent to which the central auditory nervous system (CANS) is able to accurately process and interpret information (Flood, Dumas, & Haley, 2005; Ghazanfar & Schroeder, 2006; Palfery & Duff, 2007). APD has a heterogeneous nature and can manifest in one, or several, areas within the central nervous system (ASHA, 2005; Chermak et al., 1999; Witton, 2010). Individuals of any age can be affected by APD, as this disorder has been identified in both young and older populations (AAA, 2010; ASHA, 2005). As is typical of many disorders, a wide, variable presentation of symptoms is possible and accurate diagnosis and effective intervention requires the use of an individualized approach (AAA, 2010; ASHA, 2005).

Before proceeding any further, it is necessary to discuss and clarify the terminology associated with APD. There has been much debate as to an appropriate label for this disorder, and over the years it has been referred to as Central Auditory Processing Disorder (CAPD), (Central) Auditory Processing Disorder ([C]APD), and Auditory Processing Disorder (APD). Following an APD Consensus Conference, it was recommended that the use of "central" in the title be removed because the direct site of disorder is unknown at this time, and because "central" and "processing" are considered to be redundant (Jerger & Musiek, 2000). To reflect the recommendation made by the consensus conference, APD will primarily be used in this paper.

Definition of APD.

The concept of APD was introduced in the 1950s, but the construct of the disorder has continued to evolve over the past fifty years (ASHA, 2005). With the abundance of research and case studies that has amassed since the introduction of the concept of APD, much more is known today about the nature of the disorder than was available several years ago. Along with the growth in knowledge that has occurred, several definitions of APD have been developed (ASHA, 2005; Jerger & Musiek, 2000). Currently, auditory processing "refers to the efficiency and effectiveness by which the central nervous system (CNS) utilizes auditory information" (ASHA, 1995, p. 2). This processing includes sound localization and lateralization, auditory pattern recognition, auditory discrimination, and auditory performance in the presence of competing or degraded acoustic signals (ASHA, 2005). Temporal aspects of processing including temporal ordering, integration, discrimination, and masking are also incorporated in auditory processing (ASHA, 2005). Deficits in any of these areas can occur along a continuum, as is common of many neurologic disorders, and can present differently depending on the degree and type of disorder, the environments to which the individual is exposed, and the person's ability to adapt to and compensate for his/her weaknesses (ASHA, 2005).

The ASHA Technical Report (2005) states that APD "may lead to or be associated with difficulties in higher order language, learning, and communication functions" (p. 2). Auditory processing disorder can co-occur and will commonly present in conjunction with other disorders (Witton, 2010). Since the human brain uses several different regions to accurately process and interpret sensory information, the comorbid effects are a result of the overlap seen within higher order functioning (AAA, 2010; Ghazanfar & Schroeder, 2006). However difficult, it is a necessity to distinguish the symptoms of one disorder from another and to consider the interactional, often synergistic, effects that may result from co-occurring disorders.

Prevalence.

Although APD can affect individuals of any age, it can be particularly debilitating for children in the school-age population (Jerger & Musiek, 2000). Prevalence estimates indicate that APD is exhibited in approximately 2-3% of children, presenting two times more often in boys than girls (Chermak & Musiek, 1997; Flood, Dumas, & Haley, 2005; Palfery & Duff, 2007). Auditory processing disorder can be the result of neurologic trauma or insult, but this accounts for less than 5% of affected children (Flood et al., 2005). Auditory processing disorder is often the result of maturational delays, tumors, acquired brain injuries, or infections, but can also be attributed to unknown etiologies (Flood et al., 2005). Recently, emphasis has changed from focusing specifically on the cause or site of lesion, and now focuses upon identifying how the disorder manifests itself and how it impacts the individual's daily functioning (Bamiou et al., 2001; Flood et al., 2005).

Presentation of APD.

In order to effectively manage APD patients, it is important to be aware of the classic symptoms and presentation of APD in children. Most children suspected of APD are described as appearing to have a hearing loss (Bamiou et al., 2001; Jerger & Musiek, 2000). Therefore, a complete audiological evaluation of the peripheral auditory system should always be performed prior to an auditory processing evaluation in order to rule out a hearing loss (AAA, 2010; ASHA, 2005). In order to gain a picture of the child in their real world environments, questionnaires and in-depth case histories should be completed by the child's parent(s) and school teacher(s). These data are important components of the evaluation because they can describe the daily functioning of the child and supply information that could not otherwise be obtained in a diagnostic auditory processing evaluation.

Children who present with APD are likely to exhibit behaviors that include poor listening skills, fatigue during listening situations, and difficulty with auditory memory (Colorado Department of Education, 2008; Jerger & Musiek, 2000). Language disorders, whether they are expressive or receptive, are also commonly seen in individuals identified as having APD (Sharma et al., 2009). Other general behaviors of children who have, or are at risk for, APD include difficulty understanding speech in background noise and/or difficulty with phonological awareness tasks (AAA, 2010; Jerger & Musiek, 2000). Additionally, individuals who have poor pitch pattern recognition or musical abilities may experience difficulty with the processing of temporal stimuli. Those with APD may also have trouble localizing to sound and may be easily distracted (AAA, 2010; ASHA, 2005).

As stated previously, APD does not present the same way in all individuals. A child may display only a few of the aforementioned behaviors, or they may present with many of them. These difficulties can hinder the child's performance in school and impact his/her ability to learn in a classroom without accommodations (Colorado

Department of Education, 2008). Understanding and being cognizant of the everyday signs of APD is crucial for an accurate referral and possible implementation of intervention, if necessary.

Based upon the prevalence of APD and the detrimental effects it can have on school-aged children, it is necessary to evaluate the auditory processing abilities of children who are at-risk for APD. As stated by Moore (2006), "APD is a multi-faceted label that has been used to describe an aspect of hearing that is considered or assumed to involve abnormal function in the brain's processing of sound (pg. 4)." Auditory processing disorders are consistent with decreased or dysfunctional processes associated with audition, but APD can co-occur with disorders across modalities (Chermak et al., 1999).

Comorbidity of Developmental Disorders

Due to the complex nature and organization of the human brain, it is common for weaknesses or deficits in one area of the brain to impact more than one behavior (Musiek, Bellis, & Chermak, 2005; Witton, 2010). As such, developmental disorders can co-occur and produce a synergistic effect (Witton, 2010). APD may coexist with other disorders, but unless a comorbid condition within the nervous system can be identified and confirmed, it cannot be assumed that the conditions have the same origin (ASHA, 2005).

Sensory behaviors are typically assessed individually, however, real world intellectual functioning and processing requires the simultaneous integration of inputs from multiple sensory modalities (Ghazanfar & Schroeder, 2006). Ghazanfar and Schroeder (2006) stated that an accurate understanding of the world is dependent on the brain's ability to integrate incoming information from all of the various sense organs.

With regards to the incorporation of various sensory inputs, it is inferred that a deficit in the efficient processing of auditory stimuli can, potentially, negatively influence the brain's overall ability to perceive messages containing auditory information.

Developmental disorders are not typically modality-specific, and this is evidenced by research indicating that a child diagnosed with one disorder is at a higher risk of displaying symptoms of another disorder (Witton, 2010). Witton (2010) postulated that the strong anatomical and physiological links between regions of the brain suggests that higher order cognitive processes develop together. As such, the development and interconnectedness of the brain has resulted in a high rate of co-occurring developmental disorders (Witton, 2010). Specifically, reading disorders, attention-deficit hyperactivity disorder, and language impairments are common disorders seen in individuals with APD (Sharma et al., 2009).

Since APD is considered a developmental disorder, it necessitates the use of a multidisciplinary approach (ASHA, 2005). Witton (2010) postulates that developmental disorders should be expected to co-occur. For accurate diagnoses and intervention, evaluations across disciplines are necessary to determine whether disorders truly co-occur, or whether one is the primary disorder/diagnosis while the others are secondary (Witton, 2010). Sharma et al. (2009) recommends that audiologists should work with related health professionals to select an appropriate comprehensive test battery, make an appropriate diagnosis, and develop effective management/treatment plans. An individualized approach is pertinent for children with a developmental disorder, and the likelihood of experiencing more than one disorder only increases the need (Sharma et al., 2009).

Attention-deficit hyperactivity disorder.

Attention-deficit hyperactivity disorder (ADHD) has been shown to have a high rate of co-occurrence with APD (Chermak et al., 1999; Witton, 2010). ADHD is characterized by patterns of inattention, hyperactivity, and impulsivity, and is estimated to impact approximately 5-7% of children (Chermak et al., 1999). APD and ADHD can present similarly, often making it challenging to differentially diagnose one disorder from the other (Bamiou et al., 2001). The challenge for professionals is distinguishing between the inability to attend to auditory stimuli appropriately and the associated auditory processing weaknesses versus identifying if inefficient auditory processing abilities lead to impaired attention. (Bamiou et al., 2001).

Although ADHD and APD are known to be co-morbid, Chermak et al. (1999) posit that distinctions can be drawn between the two disorders. Chermak et al. (1999) reported that pediatricians and audiologists describe the symptoms of ADHD and APD differently, with only two overlapping behaviors used to characterize both groups. The most commonly reported behaviors of each disorder are rank ordered and displayed in Table 1. Inattention and distractibility were the only two behaviors that were used to describe individuals with APD and ADHD. Further, the authors note that attention deficits manifest solely in the auditory modality in individuals with APD, whereas ADHD tends to impact more than one modality. Differential diagnosis can be difficult, but separate clinical diagnoses of APD and ADHD are possible. It should be noted, however, that co-occurring diagnoses may also be warranted (Chermak et al., 1999).

Table 1.

Common Presenting Symptoms of ADHD & APD

	ADHD	***APD***
1	Inattentive*	Difficulty Hearing in Background Noise
2	Distracted*	Difficulty Following Oral Instructions
3	Hyperactive	Poor Listening Skills
4	Fidgety/Restless	Academic Difficulties
5	Hasty/Impulsive	Poor Auditory Association Skills
6	Interrupts/Intrudes	Distracted*
7	--	Inattentive*

Note. The most commonly presenting symptoms of ADHD and APD as identified by pediatricians, according to Chermak et al., (1999).
*Indicates symptoms used to describe both ADHD and APD
Modified from Chermak et al., (1999).

It has been suggested that cognitive problems, such as inattention, listening difficulties, and communication, may underlie the clinical presentation of APD more so than the sensory processing weaknesses (Moore et al., 2010). A large scale study by Moore et al. (2010) examined the auditory processing abilities of 1,469 children between the ages of 6;0 to 11;11 years. In this study, tasks of sensory processing had a weak association with measures of communication and listening skills that are commonly considered representative of APD. Further, Moore et al. (2010) reported that poor performance on tasks of auditory processing was often attributable to inadequate cognitive abilities, such as inattention or impaired working memory. Because the results of this study suggested that in most cases, poor performance on auditory processing tasks is not directly related to an auditory impairment, Moore et al. (2010) suggested APD should be considered a disorder of cognitive and attention, rather than sensory, processes.

Prevalence estimates among those afflicted with ADHD have displayed a significant gender bias, with males being affected more often than females. Bauermeister et al. (2007) examined 1, 896 children between the ages of four and seventeen to determine if there were any gender differences associated with the risk of developing ADHD and/or the severity of the disorder. It was reported that males were 2.3 times more likely than females to be diagnosed with ADHD, and that boys experienced more severe co-morbid conditions than girls (Bauermeister et al., 2007). The prevalence estimates obtained by Bauermeister et al. (2007) were slightly lower than those reported by Szatmari, Boyle, and Offord (1989), in which estimated prevalence ranged from 3:1 and 6:1 (as cited in Bauermeister et al., 2007). The higher prevalence of ADHD in school aged boys represents the gender discrepancies often associated with brain based disorders.

Reading disorders.

Developmental reading disorders, or dyslexia, have been linked to auditory processing deficiencies (Bamiou et al., 2001; Heiervang, Stevenson, & Hugdahl, 2002; Marshall, Snowling & Bailey, 2001; Sharma et al., 2009). It has been suggested that a deficiency in the portion of the auditory system responsible for processing short duration stimuli or stimuli occurring in rapid succession may underlie reading impairments, such as dyslexia (Bamiou et al., 2001; Heiervang et al., 2002).

A study by Heiervang and colleagues (2002) examined the rapid processing abilities of non-verbal auditory stimuli in 24 children, between the ages of 10 and 12 years, with dyslexia. The results were compared to those from an age matched control group. Heiervang et al. (2002) reported that children with dyslexia were more likely to present with auditory processing weaknesses than were their age matched peers. Specifically, identifying short duration tones presented in rapid succession proved to be more difficult for children with dyslexia than for control subjects (Heiervang et al., 2002).

Breier, Fletcher, Foorman, Klaas, and Gray (2003) investigated the perception of auditory temporal and non-temporal cues in 150 children between the ages of 7;5 and 14;5 with a reading disability, with and without ADHD. The study included children with solely a reading disability (n=40), solely ADHD (n=33), a combination of a reading disability and ADHD (n=36), and normal control subjects without any known impairment (n=41). Findings suggested that individuals with a reading disability did not perform poorer than their peers on processing tasks using temporal and non-temporal cues. Those with a reading disability did, however, present with a deficit associated with detection of tone onset time asynchrony. Performance was generally poorer across all tasks for individuals with a combination reading disability and ADHD. Overall findings did not indicate auditory processing weaknesses in individuals with a reading disorder, with the exception of a test of temporal acuity (Breier et al., 2003).

Language disorders.

Individuals with specific language impairment (SLI) may present with auditory deficits similar to those described of dyslexic children by Heiervang et al. (2002), involving difficulties with rapid auditory processing (McArthur & Bishop, 2004). Language impairment is often characterized by weaknesses in the auditory processing of rapid and brief sounds and poor frequency discrimination abilities (McArthur & Bishop, 2001, 2004).

McArthur and Bishop (2004) re-examined frequency discrimination thresholds of individuals with specific language impairment who had previously been evaluated in a study by McArthur and Bishop (2001). The updated study also included eight newly recruited people, five with SLI and three controls. The SLI and control groups were each comprised of 16 people ranging in age from 12 to 21 years. Overall, results were consistent between the two evaluations, one and a half years apart, and indicated that 31% of those diagnosed with SLI have elevated frequency discrimination thresholds compared to control subjects (McArthur & Bishop, 2004). The frequency discrimination thresholds were lower for control subjects than for those with SLI for both 25 and 250 millisecond tonal stimuli (McArthur & Bishop, 2004). It is important to note that although two-thirds of those with language impairment presented with normal thresholds on tasks of frequency discrimination, the remaining one-third experienced weaknesses in this area.

The presence of APD in a population of children with a suspected learning disability was investigated by Iliadou, Bamiou, Kaprinis, Kandylis, and Kaprinis (2009). The participants consisted of 127 children between 8 and 15;11 years who, based on poor classroom performance, had been referred to a learning disabilities clinic. All participants completed a behavioral auditory processing test battery consisting of the speech in babble test, dichotic digits test, frequency pattern sequence test, duration pattern sequence test, random gap detection test, and masking level difference test. Results of this study revealed that 55 children with learning difficulties, or 43.3% of the sample, presented with APD. Further, 14 of the children in the APD group were also diagnosed with dyslexia. The authors highlighted the importance of screening for auditory processing weaknesses in the learning disabilities population, as the prevalence estimates from this study delineate the comorbidity of APD and a learning disability (Iliadou et al., 2009).

Co-occurring reading and language disorders.

Language and reading impairment are prevalent among the school aged population and these disorders often co-occur with APD (Flax et al. 2003; Sharma et al., 2009). The comorbidity of APD, reading disorder, and language impairment in 68 school-aged children between the ages of 7 and 12 years was investigated by Sharma et al. (2009). The aim of this study was to determine the percentage of children with APD who also have co-occurring reading and/or language disorders. Findings indicated that 72% (n=49) of children included in the study were diagnosed with APD, with only 4% (n=3) of these cases classified as purely APD. Approximately 47% (n=32) of children in this study presented with difficulties in all three subject areas. Attention and memory were also investigated and findings revealed that over half of the children with APD experienced difficulties with sustained auditory attention. This study was significant in that it demonstrated that more children were identified with a combination of weaknesses than were diagnosed with a single, independently occurring disorder (Sharma et al., 2009).

The co-occurrence of SLI and reading disorder in families with history of SLI was examined by Flax et al. (2003) in order to examine familial and gender prevalence. The study consisted of 22 SLI participants, matched with 26 controls, and their nuclear family members. For both SLI and reading disorders, there was a significantly increased familial incidence among males than females. Exact findings indicate that language impairment was estimated to affect 43% of males and 15% of females among families known to exhibit SLI. Similarly, reading impairment was reported to be present in 28% of males in the study, while only afflicting 18% of the females. Results once again indicate a trend demonstrating a higher male prevalence (Flax et al., 2003).

Examination of Gender Differences

As introduced in the previous section on comorbidity, the prevalence of many brain-based disorders is often higher among one gender than the other, with deficits presenting more often in males. When discussing the comorbidity of developmental disorders that often co-occur with APD, gender biases and prevalence estimates were provided. All reported data listed above highlight that males have a higher likelihood of presenting with ADHD, reading disorder, SLI, or a combination of these (Bauermeister et al., 2007; Flax et al., 2003).

Autism.

Autism is a neurodevelopmental disorder with characteristics that are often described along the autism spectrum, used as an "umbrella" term (Croen, Grether, Hoogstrate & Selvin, 2002). As cited in the DSM-IV, the characteristics of Autism form a triad of symptoms, including social impairments, repetitive behaviors, and impairments of communication (American Psychological Association [APA], 1994; Croen et al., 2002). Although the cause is unknown, Autism is believed to have a genetic component that is ultimately triggered by an environmental factor (Croen et al., 2002). Recently, the prevalence rates of Autism have increased tremendously, most likely attributable to an improvement in the ability to accurately diagnose the condition (Croen et al., 2002; Yeargin-Allsopp et al., 2003). A review of autism in a metropolitan US area by Yeargin-Allsop et al. (2003) reported an overall prevalence rate of 3.4 per 1,000 with a male to female ratio of 4:1. This evident discrepancy that exists in the prevalence between genders is not limited to autism.

Audiological differences.

Audiological differences, specifically related to the interhemispheric transfer of information, have been observed between genders (Bellis & Wilber, 2001; Jerger et al., 1994). Maturational changes of the auditory system occur over the entire lifespan, although most markedly during the first 12 years, and the efficiency with which the transfer of information throughout the auditory pathways occurs varies over time (Bamiou et al., 2001; Chermak & Musiek, 1997).

Gender differences have been examined in conjunction with age related changes on a task known as Dichotic Sentence Identification (DSI) (Jerger et al., 1994). One study retrospectively analyzed the DSI test data of 153 females and 203 males (total n=356) ranging in age from 9 to 91 years. Findings confirmed that as age increases, the right-ear advantage progressively increases, regardless of gender. Results showed that with increasing age, females experience greater deficits than males on the right ear, but smaller deficits on the left ear. Accordingly, as age increases, males experience significantly larger right-ear advantages. Males and females perform similarly on subtests that are task-related or include cognitive components, but females exhibit substantially weaker performance on auditory subtests. As such, Jerger et al. (1994) hypothesized that the gender differences observed with increasing age were caused by the auditory and structural components, although the exact structural basis is unknown.

A similar dichotic listening task, the Dichotic Digits test (DDT), has been used to examine the gender differences that develop as a result of aging. Bellis and Wilber

(2001) used this assessment, among others, to investigate the effects that aging and gender have on interhemispheric function. Participants in this study consisted of 120 adults, with equal representation of males and females, ranging in age from 20 to 75 years. Findings from this study suggested that subtle gender differences do exist, and left-ear deficits are usually present in males at an earlier age then they are in females (Bellis & Wilber, 2001). Bellis and Wilber (2001) stressed the importance of providing and using gender specific normative data for the age ranges where these differences become evident. Although the gender differences seen in aging adults are well documented, the effect of gender among children on tasks of auditory processing skills requires further investigation.

Test Battery Considerations

In order to accurately identify the presence or absence of APD, a concise, yet comprehensive test battery is necessary (ASHA, 2005). An appropriate test battery consists of behavioral assessments that are sensitive and specific in nature and which measure an individual’s auditory processing abilities. When developing a behavioral test battery, consideration should be given to factors including, but not limited to, age, language proficiency, ability to sustain attention, memory, and to the overall cognitive level or abilities of the child. There are also several considerations which need to be accounted for prior to initiating the APD test battery. As previously discussed, the likelihood of other developmental disorders co-occurring with APD is high (Bamiou et al., 2001; Chermak et al., 1999; Flax et al., 2003; Heiervang et al., 2002; Sharma et al., 2009; Witton, 2010). As such, it is important to identify the presence, or suspicion of, these potential weaknesses prior to testing. The necessity of an extensive patient history cannot be overstressed. A complete evaluation of the individual's peripheral auditory sensitivity must be performed to ensure it is within normal limits. Further, the individual's cognitive and language abilities should be determined so that an appropriate, individualized test battery can be developed. If all of the aforementioned assessments are reliably performed and interpreted, a tailored APD evaluation can be developed (ASHA, 2005).

Maturation.

Maturation of the auditory system occurs over time, with completion of myelination and maturation occurring between the ages of 10 and 12 years (Bamiou et al., 2001; Chermak & Musiek, 1997). The course of development, however, is not always consistent, and it is difficult to identify the particular status of the CANS in young children. Auditory processing abilities continue to improve with increasing age while the auditory system is continuing its development. When evaluating for APD in children, age is a critical variable. Jerger and Musiek (2000) have reported that it is hard to reliably assess auditory processing abilities with utilization of the standard tests in those under the age of 7 years. Assessment via electrophysiologic measures has provided evidence for this age criterion, as evoked potentials display inconsistent auditory functioning in children under the age of ten years (AAA, 2010; ASHA, 2005).

The variability of the CANS, in conjunction with the complexity of the auditory processing tasks included in a test battery, has limited the applicability of APD evaluations in younger children (ASHA, 2005). The limited tests that are appropriate for use with the pediatric population can be used in conjunction with behavioral checklists and screening measures to help identify children who are at-risk for developing APD

(AAA, 2010; ASHA, 2005). The use of this approach, however, does not evaluate the complete range of processing abilities, and cannot be used for diagnostic purposes (AAA, 2010; Jerger & Musiek, 2000).

Case history.

First and foremost, a comprehensive case history provides valuable information about an individual's past, as well as a brief description of current auditory strengths and weaknesses. The case history can be obtained verbally, or in a written format, and should cover a broad range of areas (ASHA, 2005). Inclusion of questions specifically related to birth, otologic, and medical histories, as well as ones addressing speech and language development, social development, and any auditory difficulties or weaknesses, among others, are considered to be effective in uncovering contributing factors of APD (ASHA, 2005). Certain assessment tools, such as checklists, may reveal specific auditory symptoms and behaviors that the individual exhibits, which are identified by an observer, typically a parent or teacher (AAA, 2010). The use of screening questionnaires can be particularly helpful in identifying areas of concern and in designing the test protocol.

Pre-test screening assessments.

Each individual should be evaluated for factors that can influence their performance on tasks of auditory processing. For example, a person's IQ (cognitive status), can affect his or her ability to complete many of the complex demands associated with well-established tests for AP, potentially resulting in false positives (ASHA, 2005). In order to eliminate the potential influence of other factors on auditory processing performance, a multi-disciplinary approach is often necessary so several professionals can collaborate and each perform individualized assessments within their scope of practice (ASHA, 2005).

Another patient factor that must be taken into consideration is the ability to sustain attention to auditory stimuli. A full-length APD test battery can be time-intensive, and as such it can be mentally tasking (ASHA, 2005). If an individual has ADHD, or if a screening test/questionnaire indicates possible attention difficulties, then the child may be unable to endure an APD battery in its entirety or may require additional breaks or motivators during the test session to ensure accurate results. It is important to identify any potential factors associated with attention, cognitive ability, or language proficiency prior to administering an APD evaluation so that a modified test battery can be implemented when necessary, and test results can be interpreted with caution.

Audiological evaluation.

Before an APD evaluation can commence, a complete evaluation of peripheral auditory sensitivity must be performed (ASHA, 2005). The following subjective and objective tests should be included in the peripheral hearing assessment: pure-tone audiometry, tympanometry, ipsilateral and contralateral acoustic reflex testing, otoacoustic emission testing, and word recognition testing (AAA, 2010). If a hearing loss of other auditory based disorder is identified, appropriate recommendations should be made prior to pursuing APD behavioral testing (AAA, 2010; ASHA, 2005).

Developing an APD test battery.

The ideal test battery would remove any confounding variables that could influence the overall results. For example, the use of speech versus non-speech stimuli needs to be considered, especially in those with language disorders. If a language disorder is present or is suspected via means of a language screening tool, tasks involving speech stimuli should be kept to a minimum so as to minimize the effect of the language weakness on the individual's overall performance (Moore, 2006). It should be noted, however, that tasks using speech stimuli are an important component of an APD test battery, as they are typically more sensitive to CANS dysfunction than tests which utilize non-speech signals (AAA, 2010; Bellis, Nicol & Kraus, 2000). Therefore, tasks, involving verbal and non-verbal signals, should be included that target various auditory processes and assess different portions of the CANS (AAA, 2010; ASHA, 2005).

Due to the heterogeneous nature and presentation of APD, children must be evaluated across a wide spectrum. The importance of a comprehensive case history cannot be stressed enough, and should include evaluations from other professionals when possible. A multi-disciplinary approach is often warranted throughout the evaluation process, and many times evaluations by speech-language pathologists and psychologists will provide access to a wealth of information and insight surrounding the child's level of functioning and, when possible, should be performed prior to the APD assessment.

Diagnosis

A specific diagnosis of APD can only be made by an audiologist using a behavioral test battery that includes tasks of varying difficulty and complexity which challenge varying levels of the CANS (AAA, 2010; ASHA, 2005). AP tests are categorized into general areas including: auditory temporal processing, dichotic listening, monaural low redundancy speech perception, and binaural interaction. It is important to include tasks from each category to provide an accurate representation of a variety of auditory processes; however, a minimum battery of sensitive and specific tests should be selected. While redundancy within the test battery should be avoided, it is recommended that two tests from each category be administered in order to provide a cross check of the results (AAA, 2010).

Several of the most commonly assessed areas of auditory processing will be discussed in detail; however, before moving forward, it is important to note that there is no currently accepted "gold standard" AP test or test battery at (AAA, 2010). ASHA (2005) recommends using an individualized approach when choosing tests and that this approach should be based on the complaints and perceived difficulties of the individual. The use of non-speech stimuli is important when assessing individuals, as it removes any confounding language factors that could influence test performance (AAA, 2010). The use of speech stimuli is important in a behavioral test battery, however, as it activates different parts of the CANS and provides information of how the brain processes speech signals. AAA (2010) recommends the use of a low-linguistic core-test battery, which can be supplemented and individualized with additional tests of increasing linguistic complexity.

Temporal processing tasks.

One important component of a behavioral APD test battery contains tests of various temporal processing and patterning abilities (AAA, 2010; ASHA, 2005). The aim of these tests is to evaluate the listener's ability to analyze auditory events that occur over time, and examples of tasks in this category include forward and backward masking, temporal sequencing, temporal patterning, and gap detection (ASHA, 2005). Auditory temporal processing refers to an individual's perception of the temporal and durational characteristics of a sound (Musiek et al., 2005). Auditory processing takes place over a period of time, and therefore, the accurate processing of a verbal or nonverbal stimulus requires that the time structure of the signal is preserved by the auditory system (Musiek et al., 2005). As such, weaknesses in the area of temporal processing may underlie many cases of APD (Musiek et al., 2005).

Several tests are currently available for use with assessing temporal processing abilities. A reliable way to assess temporal resolution is by administering the Random Gap Detection Test (RGDT) or Gaps-in-Noise (GIN) Test, which will evaluate within-channel gap detection abilities (Keith, 2000b; Musiek et al., 2005). These tests of temporal resolution measure the ability of the auditory system to react to rapid changes in a stimulus (Musiek et al., 2005). Tests of temporal sequencing and patterning, such as the Frequency Pattern Test (FPT) and Duration Pattern Test (DPT), have also been evidenced to be valuable measures for the assessment of APD (AAA, 2010; Musiek, Baran, & Pinheiro, 1990).

Dichotic listening tasks.

A second category of behavioral tests that is typically included in an APD assessment measures dichotic listening abilities. Available tests of dichotic listening utilize various test item stimuli, including numbers, words, and sentences (Fifer, Jerger, Berlin, Tobey, & Campbell, 1983; Meyers, Roberts, Bayless, Volkert & Evitts, 2002; Musiek, 1983a). Dichotic listening tasks require the listener to process more than one event, one in each ear, simultaneously (Meyers et al., 2002). It assesses the listener’s ability to either separate or integrate the information presented to each ear (ASHA, 2005). These tests have been proven to be sensitive to weaknesses of the auditory system, and as such, are integral in assessing auditory processing abilities (Jerger & Martin, 2006;

Musiek, Gollegly, Kibbe, & Verkest-Lenz, 1991). The DDT (Musiek, 1983) and the Staggered Spondaic Word (SSW) Test (Katz, 1968) are common clinically administered assessments of dichotic listening abilities.

The performance ability of children and adults on the DDT has been evaluated by Moncrieff and Wilson (2009) in order to examine developmental differences between groups. The study consisted of 278 individuals between the ages of 10 and 28 years who were divided into groups based upon chronological age. Normative data was collected and interaural asymmetries were calculated based on the difference between ear scores. Overall findings indicated that performance increased with age, especially for the left ear, with ceiling effects emerging in the older adults. In children, left ear performance was typically worse, and the difference between ear scores lessened with age. Moncrieff and Wilson (2009) report that the performance on the DDT appears to increase until approximately 18 years of age, with individuals between 19 and 28 years performing significantly better than those 18 years and younger. Normative data are provided by this study for age-related comparison for the one-, two-, and three-digit conditions, and the use of the DDT to assess binaural integration is condoned (Moncrieff & Wilson, 2009).

Jerger and Martin (2006) studied the use of dichotic listening for the evaluation of APD. Specifically, they examined if the test mode, which is the manner in which a test is administered, affected the overall results. Various conditions were examined including divided attention (free recall), directed attention, and divided attention with pre-cued direction. In the divided attention condition, the listener must repeat all test stimuli heard in both ears, as is the protocol for the DDT. Tasks utilizing this mode of response require an appropriately fast mental processing speed and adequate auditory memory abilities, which can be challenging in the pediatric population. These same limitations exist for tests such as the Competing Words subtest of the SCAN 3, which instruct the listener to repeat back information heard in both ears, but to report the information presented to one ear first (Keith, 2009). When the right side is pre-cued for the listener, the right ear advantage is typically larger. Conversely, tests in the divided attention mode require the listener to repeat information presented to one ear, which was pre-cued, while ignoring the information presented to the other ear. The Competing Sentences Test is administered in this form, and it has been reported that the influence of memory, attention, and processing speed are reduced with this technique (Keith, 2009). Also of interest, right ear advantages are minimized as compared to the other two modes of test administration (Jerger & Martin, 2006).

Overall findings of the Jerger and Martin (2006) study suggest that tasks of dichotic listening are affected by the way in which the test was administered. Extra-auditory confounds may influence test results, especially for some test modes. Therefore, it is recommended that clinicians assess dichotic listening tasks in two different domains, including divided- and directed-attention modes, to compare results, weaknesses, and deficits (Jerger & Martin, 2006).

Calculating ear scores for dichotic tests provides additional information of hemispheric function (AAA, 2010). A right-ear advantage will commonly exist on tasks of dichotic listening, and this advantage will decrease as the auditory system matures. Tasks within the category of monaural low redundancy, however, should reveal ear scores that are not significantly different. The presence of left-ear advantages or an inflated right-ear advantage beyond the age at which the auditory system should be mature should raise concerns for potential CANS dysfunction (AAA, 2010).

Monaural low redundancy tasks.

Tests of monaural low redundancy represent another category of behavioral tests with which to evaluate APD. Monaural low redundancy tasks are not as sensitive to the presence of APD as compared to dichotic listening and temporal processing tests (AAA, 2010); however, they are applicable to the day-to-day functioning of a person and are particularly useful in developing appropriate management techniques. Tests in this category assess an individual's functional auditory closure abilities and assess speech understanding of a degraded quality signal (AAA, 2010; ASHA, 2005). Techniques used to degrade the stimuli for tests of this type include time compression, low- and high-pass filtering of specific frequencies, and the presentation of competing background noise to contaminate the speech signal (AAA, 2010). The Compressed and Reverberated Words (CRW) test is an assessment contained within the category of monaural low-redundancy, in which time compression and reverberation are used to degrade the signal of interest and evaluate the listener's ability to understand speech in less than ideal situations (Wilson, Preece, Salamon, Sperry, & Bornstein, 1994).

A new and innovative test, known as the Listening in Spatialized Noise Test-Sentences test (LiSN-S), provides a way to assess binaural low redundancy and localization abilities (Cameron & Dillon, 2007a). The Listening in Spatialized Noise Test (LiSN) was originally developed to measure speech understanding in the presence of background noise (Cameron, Dillon, & Newall, 2006). The LiSN-S was developed from the LiSN to assess auditory stream segregation skills and the ability to understand speech in the presence of background noise, as it produces a three-dimensional listening environment through utilization of headphones and consists of four listening conditions (Cameron & Dillon, 2007a). This test adds a new dimension to the APD test battery.

Overall findings of an experimental study of the LiSN-S suggested that performance improves as age increases, as evidenced by decreasing SRTs and increasing advantage scores (Cameron & Dillon, 2007a). It is recommended that the LiSN-S be utilized clinically for children who are at least six years of age, as the normative data suggested that binaural processing abilities are still developing in children younger than this (Cameron & Dillon, 2007a). The LISN-S is a relatively easy test to administer, taking approximately 12 minutes to complete all four listening conditions, in order to evaluate the lateralization skills of children (Cameron & Dillon, 2007a). Further, the performance differences between the test and retest conditions are significant, but small, ranging from 0.1 to -1.3 dB across listening conditions, suggesting that the LiSN-S provides a reliable measure of performance over time (Cameron & Dillon, 2007c). Although the LiSN-S is linguistically loaded, it provides an effective way to assess auditory figure ground and localization abilities in young children with suspected APD. The LiSN-S test was originally developed in Australia; however, the North American Listening in Spatialized Noise-Sentences Test (NA LISN-S) has been recorded for use in the United States and Canada, utilizing native North American speakers (Cameron et al., 2009). Similar results and normative data were obtained for the NA LiSN-S, with performance increasing in conjunction with increasing age, suggesting that the NA LiSN-S is an effective test for use with children in order to assess auditory stream segregation abilities (Cameron et al., 2009).

Although there is not a standard APD test battery that should be administered consistently, the behavioral tests described above constitute a well-rounded assessment of a variety of auditory processes (ASHA, 2005). As recommended by AAA (2010), administration of the minimal amount of tests necessary to appropriately and accurately evaluate a majority of the auditory processes should be considered protocol for the evaluation of children. If persistent difficulties in one particular category are apparent, more assessments may be administered to gather more details (AAA, 2010). Due to the heterogeneous nature of APD and the variable presentation of individuals within this population, flexibility within the test battery is needed.

In order to diagnose the presence of APD and aid in the interpretation of test results, age-based normative data are used routinely (ASHA, 2005). A score that is two or more standard deviations below the mean on two different behavioral tests of auditory processing is interpreted to be positive for APD (Bellis, 2003). A failure on one behavioral test by three or more standard deviations can also be considered evidence of an APD; however, if possible, the failed assessment should be repeated and a supplemental test in the failed category should be administered (ASHA, 2005). Therefore, comparisons to these established norms can provide insight as to what is normal versus abnormal, and examination of specific test results can help to identify specific auditory strengths and weaknesses. Ear advantage scores can be calculated and provide information regarding hemispheric dominance and potential hemispheric asymmetries (AAA, 2010). It is always important to interpret test results with caution. Consideration of any confounding factors that may have influenced test results is necessary and all such concerns should be documented (ASHA, 2005).

Development of Normative Data

In order to reliably identify the presence or absence of normal auditory processing abilities, test performance must be compared to age-specific normative data (AAA, 2010). As the auditory system matures, the complexity of the tasks that can be successfully performed typically increases (Moore et al., 2010). As such, the criterion scores are higher for older children and for adults than for younger children with immature systems. It is critical to develop normative data based upon typically developing subjects with normal listening skills. Auditory processing disorder has been evidenced to commonly co-occur with other conditions and auditory processing abilities are substantially influenced by certain patient factors and patient state. Therefore, the individuals assessed for the development of normative data cannot exhibit any of the characteristics that can affect overall test performance.

Studies similar in scope to this one have been performed in order to develop age-appropriate normative data for behavioral tests of auditory processing. One such study by Kelly (2007) developed normative data based upon 129 New Zealand school children between the ages of 7 and 12;11 years. The tests contained in the behavioral test battery included the Frequency Pattern Test (FPT), Random Gap Detection Test (RGDT), DDT, and CRW test. Participants were classified into three age groups to examine the effect of maturation on performance. Results revealed that performance on all tests, with the exception of the RGDT, was affected by age, with overall performance improving with increasing age. Specific normative data by ear and age group were provided (Kelly, 2007).

Gender differences have been observed among a variety of disorders, and substantial discrepancies exist in association with reading disorders, ADHD, Autism, and language disorders (Bauermeister et al., 2007; Croen et al., 2002; Flax et al., 2003; Yeargin-Allsop, 2003). Prevalence estimates indicate that all of these disorders are more commonly exhibited by males than females (Bauermeister et al., 2007; Croen et al., 2002; Flax et al., 2003; Yeargin-Allsop, 2003). Because the prevalence of these disorders is greater in males, and because all of these disorders may co-occur with the presence of APD, it is suspected that gender differences may exist for APD, as well. Further research is necessary to investigate the possible influence of gender on auditory processing abilities throughout a variety of age groups. If differences among normative APD test results were detected between genders, normative data would need to be specified for each gender to provide as much sensitivity and specificity as possible.

It is further suggested that updated normative data be established within local areas (AAA, 2010). The purpose of this study is to examine the influence of gender on the auditory processing abilities of typically developing children between the ages of 7;0 and 12;11 years and to use these data to develop normative data on a core test of auditory processing for use with individuals of this age group.

CHAPTER 3

Methodology

Participants

Prior to recruitment of participants, Institutional Review Board (IRB) approval was obtained for this research study, as can be seen in Appendix A. All participants in this study were selected on a voluntary basis. Twenty-eight typically developing children between the ages of 7;0 and 12;11 (years; months) were recruited primarily from public and private elementary and middle schools in the greater Baltimore County area and from local community centers (i.e., swimming pools). Additional resources for recruitment included flyers (Appendix E) posted to various bulletin boards and through word of mouth. Test sessions were conducted at times that did not conflict with the participants' school schedules, including weekends and school holidays. All participants were compensated monetarily for their inclusion in this research study.

Participants were divided into three groups according to chronological age, with a focus on achieving a balance between genders in each subgroup. The participants were divided into the following age ranges: 7;0-8;11, 9;0-10;11, and 11;0-12;11. For inclusion in this study, a parent/guardian was required to complete a written case history form (Appendix B) and to provide Informed Consent (Appendix C) expressing their agreement for the child to participate. Additionally, each child signed an Informed Assent (Appendix D) affirming their participation in this research study prior to beginning any testing.

Pre-screening.

Parents of interested participants were contacted over the phone or via email prior to scheduling a test date. The following questions were asked to all parents in order to identify if the child was a candidate for the research study: (1) Is English the child's first language?, (2) Did the child meet all developmental milestones age-appropriately?, (3) Did the child meet all speech and language milestones at appropriate ages?, (4) To the best of your knowledge, does your child have normal hearing, reading, speech, and language abilities?, and (5) Does your child currently have any diagnoses (i.e. ADHD)?

Equipment

All testing was performed at the Towson University Speech, Language, & Hearing Center (TU-SLHC) in Towson, Maryland. Audiological and auditory processing testing was administered in a sound treated, double-walled IAC (Industrial Acoustics Company) sound booth. To avoid any potential bias, test order was randomized for all behavioral tests and all pre-test assessments among all participants. Audiometric testing, used to confirm normal hearing sensitivity, and auditory processing testing was performed using the Grason-Stadler, GSI-61, audiometer. ER-3A insert earphones were utilized for all audiological and auditory processing assessments. The GSI-61 audiometer was calibrated according to American National Standards Institute (ANSI) standards and a biologic listening check was performed each day prior to testing. Tympanometry and ipsilateral and contralateral acoustic reflex testing was performed using the Grason-Stadler (GSI) Tympstar Middle Ear Analyzer which was calibrated according to ANSI standards. Transient Evoked Otoacoustic Emissions (TEOAEs) were obtained from 1000-4000 Hz bilaterally using the ILOv6 software, which was calibrated prior to each test session. A child case history form developed for this study was completed by each participant's accompanying parent upon arrival at the test session.

All tests included in the behavioral auditory processing test battery were administered using recorded materials. The Veterans Administration (VA) compact disc for Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 2.0, was used to administer the Frequency Pattern Test (FPT) (Musiek, 1994), Duration Pattern Test (DPT) (Musiek, 1994), Dichotic Double Digits Test (DDT) (Musiek, 1983a), and Time Compressed and Reverberated Words Test (CRW) (Wilson et al., 1994). The Auditec Random Gap Detection CD was utilized to administer the Random Gap Detection Test (RGDT). The SCAN-3:C CD was used to administer the auditory figure ground subtests of the SCAN-3:C (Keith, 2009). The LiSN-S test was administered using the LiSN-S software on an external laptop (Cameron & Dillon, 2007b). Test items for the LiSN-S were presented via Sennheiser HD 215 headphones. An external CD player, which is routed through both channels of the audiometer, was used to present all recorded test stimuli through the GSI-61. Both compact discs were calibrated so that the VU meter peaked at 0 dB HL for both channels of the audiometer using the calibration tone provided on the CDs.

Several resources were used to appropriately screen each participant's speech and language abilities, non-verbal intelligence, phonological memory, and attention. The Test of Nonverbal Intelligence-3 (TONI-3) Picture Book were used to administer this test. In order to screen for language disorders, the Clinical Evaluation of Language Fundamentals-4 (CELF-4) Screener Stimulus Book was utilized and all responses were documented on the record form. The Comprehensive Test of Phonological Processing (CTOPP) was administered using the CTOPP picture book and responses were noted in the corresponding record booklet. Finally, the Integrated Visual and Auditory-

Continuous Performance Test (IVA-CPT) was used to assess each participant's auditory and visual attention. A laptop and external mouse were used to present the stimuli needed to complete this task.

Audiological Assessment

In order to quantify that all participants have normal peripheral auditory sensitivity, a pure tone hearing screening was performed bilaterally at 15 dB HL for all octave frequencies from 250-8000 Hz. Each participant was instructed to push a button or raise their hand in response to each presentation of an auditory stimulus. Word recognition score (WRS) testing was performed using the CID-W22 word lists. The test was administered in quiet at a presentation level of 55 dB HL.

Middle ear function was evaluated in conjunction with the peripheral hearing screening. Tympanometric data was obtained bilaterally to ensure normal tympanic membrane/middle ear system mobility and pressure, as indicated by Jerger Type A tympanograms (Jerger, 1970). Ipsilateral and contralateral acoustic reflex thresholds (ART) were assessed to evaluate outer and middle ear function. ARTs were performed at 500, 1000, and 2000 Hz in this ipsilateral and contralateral conditions for stimulation of both the right and left ears.

Transient Evoked Otoacoustic Emissions (TEOAEs) were assessed from 1000-4000 Hz bilaterally using the ILOv6 software. This test records a response from the outer hair cells of the cochlea. "Normal" responses were quantified according to the signal to noise ratio (SNR) obtained at each test frequency. A SNR of greater than 3 dB at 1000 Hz and greater than 6 dB from 2000-4000 Hz was designated as the passing criteria.

Participants were required to pass at least three of the test frequencies in each ear for inclusion in the study.

Behavioral Auditory Processing Test Battery

A comprehensive behavioral test battery was administered to assess the auditory processing abilities of each participant. Seven tests, comprising four general areas of auditory processing, were included in the battery. Three tests of temporal processing, one test of dichotic listening, two tests of monaural low redundancy, and one test of auditory figure ground/localization, were completed for each of the thirty participants. All tests were consistently administered at a comfortable listening level of 60 dB HL. It should be noted that directions were provided and practice items were completed prior to the start of each assessment. Listening breaks of varying length were provided in order to avoid fatigue as needed throughout the test battery on an as needed basis. Additionally, a summary chart of the auditory processing test battery can be found in Table 2.

Tests of temporal processing.

The FPT was administered in a monaural arrangement in order to assess the temporal patterning abilities of the brain (Musiek, 1994). Three tones of either low (880 Hz), or high (1122 Hz), frequency were presented in a monaural fashion, to one ear at a time. All of the tones had a duration of 150 milliseconds and were separated by a 200 millisecond interval. The participant was required to verbally state the frequency pattern of the three tones, for example, “high-low-high,” and humming was not permitted. Five practice items were administered. Fifteen test items were presented to each ear separately. If one or more segments of the test item were identified incorrectly, it was considered to be wrong. Scoring for the FPT was calculated by determining the percent correct obtained for both the right and left ears. More specifically, the number of correctly identified items for each ear was divided by 15, as there were 15 total test items (Musiek, 1994).

Table 2

Summary of Auditory Processing Test Battery

Test	Presentation Level	Stimuli	Presentation Mode	Process Assessed	Task
FPT	60 dB HL	880 Hz (low) or 1122 Hz (High) 150 ms tones	Monaural	Temporal	Verbally state pattern of 3 tones (low and high)
DPT	60 dB HL	250 ms (short) or 500 ms (long) 1000 Hz tones	Monaural	Temporal	Verbally state pattern of 3 tones (short and long)
RGDT	60 dB HL	Pairs of 500, 1000, 2000, and 4000 Hz tones with random ISI from 0 to 40 ms	Binaural	Temporal	Verbally state whether one or two tones were heard
DDT	60 dB HL	Digits 1-10 (excluding 7) Male Speaker	Binaural	Dichotic	Repeat all 4 numbers in any order
CRW	60 dB HL	Monosyllabic NU-6 words with 45% compression and 0.3 s reverberation Female speaker	Monaural	Monaural low redundancy	Repeat the word after the carrier phrase
AFG	50 dB HL (0 / +8 dB SNR)	Monosyllabic words in the presence of multi-talker babble; low-pass filtered at 1000 Hz	Monaural	Monaural low redundancy	Repeat words in the presence of background noise
LiSN-S	Competing speech constant at 55 dB SPL and target speech initially at 62 dB HL (+7 dB SNR)	Sentences in 4 conditions: different voices $\pm$ 90°, same voice $\pm$ 90°, different voices $\pm$ 0°, same voice $\pm$ 0°	Binaural	AFG / Localization	Repeat as many words as possible after hearing each target sentence

Note. FPT = Frequency Pattern Test; DPT = Duration Pattern Test; RGDT = Random Gap Detection Test; ISI = Interstimulus Interval; DDT = Dichotic Digits Test; CRW = Compressed and Reverberated Words; NBN= narrowband noise; AFG = auditory figure ground subtest of the SCAN 3:C, SNR = signal-to-noise ratio

Modified from Dau, L. (2011).

The DPT was also administered to assess the brain's ability to perform temporal patterning tasks (Musiek, 1994). Test stimuli consisted of 1000 Hz tones of varying duration that were presented in a monaural arrangement. Each tone was either short (250 msec) or long (500 msec) in duration. The participant was required to verbally repeat the duration pattern of the three tones, such as "short-short-long." Five practice items were administered prior to starting. The DPT consisted of 30 total test items, with 15 test items presented to each ear separately. If any segment of the test item was repeated back incorrectly, the item was marked incorrect. Scoring for the DPT consisted of once again calculating the percent correct obtained for each ear as is protocol for scoring of the FPT (Musiek, 1994).

The RGDT was administered to assess temporal resolution (Keith, 2000b). During the RGDT, each participant was presented with four separate subtests of tones at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz respectively. Each subtest contained tone pairs with varying interstimulus intervals, ranging from 0, 2, 5, 10, 15, 20, 25, 30, and 40 milliseconds, presented in a randomized order. For each presentation, the participant was required to verbally identify if there was one or two stimulus tones. The lowest identified gaps for each frequency were averaged together to determine the patient's composite gap score in milliseconds (Keith, 2000b). The gap detection threshold was averaged across the four frequencies to determine the composite gap detection threshold, unless the data for one frequency was inconsistent (i.e., if the child identified a 5 msec presentation as two tones, but a 20 msec presentation as one tone), in which case results were averaged across the remaining three frequencies.

Test of dichotic listening.

The DDT was presented in a binaural arrangement (Musiek, 1983). The test stimuli consisted of the digits one to ten, excluding the number seven. Each test item involved the presentation of two numbers to each ear simultaneously, for a total of four digits. The participant was required to repeat back all four digits that they heard. Responses could be repeated back in any order, as the order of items was not included in the scoring process. Five practice items were administered to ensure the participant understood the nature of the task. Twenty double digit test items were administered. If one or both digits were repeated back incorrectly for any test item, the item was determined to be wrong. The number of correct responses was totaled for each ear and divided by 20, as there are 20 total test items, in order to obtain a percent correct score for each ear (Musiek, 1983).

Tests of monaural low redundancy.

The CRW test was administered as an additional task of monaural low redundancy (Wilson et al., 1994). The test stimuli consisted of distorted monosyllabic NU-6 words that have undergone 45% time compression and have 0.3 seconds of reverberation. The test was presented in a monaural arrangement in which 50 test items were provided to each ear separately, for a total of 100 test items. The participant was required to repeat back the word that comes after the carrier phrase. Five practice items were presented prior to the beginning of the test. A percent correct score was calculated for both the right and left ears by totaling the number of correct responses in each ear and dividing by fifty (Wilson et al., 1994).

Two auditory figure ground assessments from the SCAN-3:C Tests for Auditory Processing Disorders in Children were administered to evaluate monaural low redundancy abilities (Keith, 2009). In the first subtest, test stimuli were presented at a +8 dB signal-to-noise ratio (SNR), whereas test items in the second subtest were administered at a 0 dB SNR relative to the multi-talker babble. The administration of these two tests varied, as test order was randomized. These subtests assessed the child's ability to understand speech in the presence of background noise. The test stimuli consisted of one syllable words in the presence of multi-talker babble. Two practice items were presented to each ear prior to administration of the test items. There were 40 total test stimuli were presented, with 20 words administered to each ear separately (Keith, 2009).

Test of auditory figure ground/localization.

The Listening in Spatialized Noise-Sentences (LiSN-S) test was administered to assess auditory stream segregation skills (Cameron & Dillon, 2007c). This test consisted of four listening conditions which were as follows: (1) Different Voices +/- 90°, (2) Same Voice +/- 90°, (3) Different Voices 0°, and (4) Same Voice 0°. The target sentence was perceived as coming from 0° azimuth, or directly in front of the listener. The maskers varied according to their perceived location (0° versus +/- 90° azimuth) and the vocal presentation identity of the speaker (same versus different), or both. A target sentence stimulus was presented to the child in the presence of competing background noise. The child was instructed to respond by repeating back the sentence that was presented as accurately as possible. A 1000 Hz warning tone was presented prior to each sentence to alert the listener to the task. The competing speech was presented at 55 dB SPL. The target sentences were presented at a starting level of 62 dB SPL (+7 dB SNR) and then automatically adjusted in each listening condition to determine the listener's speech reception threshold (SRT). Following the presentation of each sentence, the SNR was adjusted based on the number of words the listener correctly identifies. If more than 50% of the words in the sentence were correctly identified, the amplitude of the next sentence was reduced, whereas if less than 50% of the words were correctly identified, the amplitude of the next sentence was increased. The level of the sentences were be altered by 4 dB until the first upward reversal was noted, after which 2 dB steps were used. A maximum of 30 sentences were presented in the four listening conditions. Testing and scoring for each listening condition was performed through the LiSN-S software program. The test administrator recorded the number of correctly identified words in each sentence in the computer software following each stimulus presentation. The LiSN-S SRT can be considered the SNR that represents 50% intelligibility. The SRT was calculated following completion of each listening condition. Overall results provided two SRTs (high cue and low cue) and three "advantage" measures, which represent the amount of dB gained when integrating different spatial cues, talkers, or a combination of both into the maskers (Cameron & Dillon, 2007c).

Additional Tests

Nonverbal IQ.

The Test of Nonverbal Intelligence (3rd Edition), or TONI-3, was administered as a language-free measure of cognitive skills (Brown, Sherbenou, & Johnsen, 1997). The test consisted of 45 test items that appeared in order of increasing difficulty. The TONI-3 assessed problem solving skills without the use of language in the directions, test material, or responses. Minimal instructions were provided and all necessary instructions for task completion were modeled (non-verbally) to each participant prior to test administration. The TONI-3 test booklet, which displays one item per page, was placed on the table between the test proctor and the participant. Responses for this particular task required the participant to point to the item on the page that completed the given pattern. Five practice items were completed to confirm that the participant understood the task at hand. All testing was administered according to instructions and all responses were documented on the TONI-3 Form A or Form B Answer and Record Form (Brown et al., 1997).

Language.

The Clinical Evaluation of Language Fundamentals (4th Edition) (CELF-4) screening test was used to screen for a language disorder which could adversely influence a participant's performance during the APD assessment (Semel, Wiig & Secord, 2003). Participants in the youngest age group, between the ages of 7;0 and 8;11, were only administered items 1-28. All other participants, ranging in age from 9;0 to 12;11, were required to complete test items 14-47. Prior to the start of each category of the test, a practice item was performed that did not count towards the overall score. All responses were recorded on the accompanying CELF-4 answer sheet. Each participant's raw scores were converted to an age-matched criterion score (Semel et al., 2003). The test instructions, administration, and scoring were conducted according to the manual.

Phonological processing.

In order to evaluate each participant's phonological awareness, phonological memory, and rapid automatic naming abilities, the Comprehensive Test of Phonological

Processing (CTOPP) was administered (Wagner, Torgesen, & Rashotte, 1999). This particular test was used to identify any participants whose phonological processing abilities were below the normal limits for their chronological age. The following six subtests from the CTOPP were included in the screening evaluation: Elision, Blending Words, Memory for Digits, Rapid Digit Naming, Nonword Repetition, and Rapid Letter Naming. These subtests comprised the areas of Phonological Awareness (Elision and Blending Words), Phonological Memory (Memory for Digits and Nonword Repetition), and Rapid Naming (Rapid Digit Naming and Rapid Letter Naming). A core composite score was calculated for each of the categories, and compared to normative data (Wagner et al., 1999). The test instructions, administration, and scoring were conducted according to the manual.

Sustained attention.

The Integrated Visual and Auditory-Continuous Performance Test (IVA-CPT) was administered to assess each participant's sustained auditory and visual attention (Sandford & Turner, 1995). The test consisted of the numbers "1" and "2" presented both visually and auditorily in a randomized order. Each child was required to sit in front of a computer screen and click the mouse anytime they saw or heard the target stimulus, the number "1." In contrast, the child was instructed not to click the mouse in response to the opposing stimulus, the number "2." The IVA-CPT provided an indication of the impulsivity and inattention errors obtained throughout the test. There was a practice phase to this test which was administered prior to the start of testing. The results of this assessment were particularly important in determining if a participant displayed an appropriate level of sustained attention, to both auditory and visual stimuli, necessary to complete the behavioral auditory processing evaluation (Sandford & Turner, 1995).

Exclusionary Criteria

The exclusionary criteria was based on failure on one or more of the following items: (1) audiological assessment, (2) CELF-4, (3) CTOPP, (4) TONI-3, (5) or any component of the APD test battery in comparison to nationally published normative data as provided by Bellis (2003). Failure on the IVA-CPT did not serve as a definitive exclusionary measure if there were no other diagnoses or indicators of potential attention disorders. If the exclusionary criterion was not met for any participant, his or her data was not included in the final analysis.

Statistical Analysis

Once all participant data was collected, statistical analyses were performed to evaluate the findings. Descriptive statistics and statistical analyses were performed on the additional test and behavioral APD test battery data using the IBM SPSS Statistics version 19 and Microsoft Excel 2010. One-way Analysis Of Variance (ANOVA) tests were performed to determine if the dependent factors of age group (7-8 years versus 9-10 years versus 11-12 years), gender (male versus female), and ear (left versus right) had statistically significant effects on the independent measure, the mean scores of each auditory processing assessment. Additionally, a bivariate correlation was performed to evaluate the relationship between the factors of nonverbal IQ scores, sustained auditory attention scores, handedness, and a musical instrument on the mean auditory processing test scores.

Chapter 4

Results

Participants

This study investigated the auditory processing abilities of 28 typically developing children between the ages of 7;0 and 12;11 years. The data from all participants was included in the statistical analyses, except for one 11 year old male, who was excluded due to a bilateral conductive hearing loss. The remaining 27 participants, 13 males and 14 females, were divided into the following three age groups: 7;0-8;11, 9;0-10;11, and 11;0-12;11. The overall mean ages of the participants were 9.61 (1.78) for the male group and 9.88 (1.56) for the female group. The specific chronological ages of the 27 participants and the overall mean and median ages of the male and female participants can be seen in Table 3.

Additional Information

As reported by the case history forms completed by each participant's parent/guardian, several other factors were recorded as means of obtaining additional information. All 27 participants spoke English as their primary language. Seventeen of the participants have previously and/or currently play a musical instrument. All but six of the participants are right handed. Otologically, 15 of the participants, or 55.56%, had a history remarkable for ear infections and two of the participants had a history significant for Pressure Equalization (P.E.) tubes. Additionally, two participants were diagnosed with ADHD, and both took their prescribed medication prior to testing.

Table 3.

Participant Age Statistics

Participant #	Males (n=13)	Females (n=14)
7-8 Years		
1	8.67	8.17
2	8.25	7.83
3	7.08	8.83
4	7.42	7.33
5	7.58	8.92
Mean	7.8 (0.64)	8.22 (0.67)
9-10 Years		
1	10.25	9.92
2	9.67	10.92
3	10.08	9.5
4	10.92	9.75
5	9.17	10.25
Mean	10.02 (0.65)	10.07 (0.55)
11-12 Years		
1	12.0	11.08
2	12.67	12.58
3	11.17	11.75
4	--	11.42
Mean	11.95 (0.75)	11.71 (0.64)
Mean Age	**9.61(1.78)**	**9.88 (1.56)**
Median Age	**9.67**	**9.84**

Note. The exact chronological ages of all 27 participants, displayed in years, are listed according to gender and the age group into which they were categorized. The mean age for each gender was calculated for each age group. The mean and median ages were also calculated across all male and female participants. Standard deviation values are expressed in parentheses.

Audiological Assessment

Audiometric testing was performed prior to completing the auditory processing test battery to establish that each participant's peripheral hearing was within the normal range. All participants included in the data analysis passed an audiometric pure tone screening performed at 15 dB HL from 250-8000 Hz bilaterally. Word recognition scores were obtained and all participants' scores ranged between 96% and 100% bilaterally.

Tympanometry results revealed 25 participants with Jerger Type A tympanograms bilaterally, one participant with Type A_D tympanograms bilaterally, and one participant with an A_D tympanogram for the right ear and a Type A tympanogram for the left ear. Ipsilateral and contralateral acoustic reflex threshold (ART) testing was performed for 500, 1000, and 2000 Hz bilaterally. It should be noted that threshold levels of 115 dB HL were entered during data analysis for one participant who did not have measurable ART responses at 500, 1000, and 2000 Hz for the left contralateral condition and at 1000 Hz for the right contralateral condition. The means and standard deviations for ARTs can be seen in Table 4.

Table 4.

Ipsilateral Acoustic Reflex Threshold Data

		Right Ear (dB)			**Left Ear (dB)**		
		500 Hz	***1000 Hz***	***2000 Hz***	***500 Hz***	***1000 Hz***	***2000 Hz***
Males	***7-8 Years***	88 (5.70)	90 (3.54)	89 (2.24)	91 (4.18)	91 (4.18)	89 (4.18)
Males	***9-10 Years***	90 (5.00)	89 (5.48)	89 (8.22)	90 (3.54)	87 (4.47)	91 (5.48)
Males	***11-12 Years***	95 (8.66)	93.33 (5.77)	93.33 (7.64)	95 (0)	93.33 (2.89)	90 (5.00)
Females	***7-8 Years***	87 (6.71)	87 (4.47)	87 (5.70)	86 (6.52)	83 (7.58)	85 (7.91)
Females	***9-10 Years***	90 (7.07)	89 (4.18)	89 (2.24)	94 (4.18)	93 (4.47)	91 (2.24)
Females	***11-12 Years***	90 (7.07)	91.25 (4.79)	91.25 (4.79)	91.25 (6.29)	90 (4.08)	91.25 (4.79)

Contralateral Acoustic Reflex Threshold Data

		Stimulus Right Ear (dB)			**Stimulus Left Ear (dB)**		
		500 Hz	***1000 Hz***	***2000 Hz***	***500 Hz***	***1000 Hz***	***2000 Hz***
Males	***7-8 Years***	94 (5.48)	94 (5.48)	91 (4.18)	95 (7.07)	96 (5.48)	93 (4.47)
Males	***9-10 Years***	98 (5.70)	97 (5.70)	95 (6.12)	94 (4.18)	94 (6.52)	94 (5.48)
Males	***11-12 Years***	101.67 (7.64)	105 (8.66)	101.67 (7.64)	100 (13.23)	100 (13.23)	103.33 (10.41)
Females	***7-8 Years***	90 (6.12)	89 (7.42)	88 (7.58)	94 (5.48)	91 (4.18)	93 (8.34)
Females	***9-10 Years***	96 (4.18)	99 (2.24)	98 (2.74)	96 (2.24)	95 (3.54)	94 (4.18)
Females	***11-12 Years***	97.5 (6.45)	97.5 (6.45)	96.25 (4.79)	96.25 (8.54)	96.25 (6.29)	95 (4.08)

Note. The mean ipsilateral and contralateral acoustic reflex thresholds, measured in dB HL, are displayed above for 500, 1000, and 2000 Hz, according to gender and age group. The standard deviation values for each condition are contained in parentheses. All results are displayed according to the ear to which the stimulus was applied.

Outer hair cell function was assessed from 1000-4000 Hz bilaterally using Transient Evoked Otoacoustic Emission (TEOAE) testing. The results indicated that the female participants had higher mean SNR than the male participants for all conditions except for the right ear at 1000 and 1400 Hz. Group mean SNR and standard deviations for all 27 participants can be seen Figure 1 with exact values in Table 5.

Figure 1.

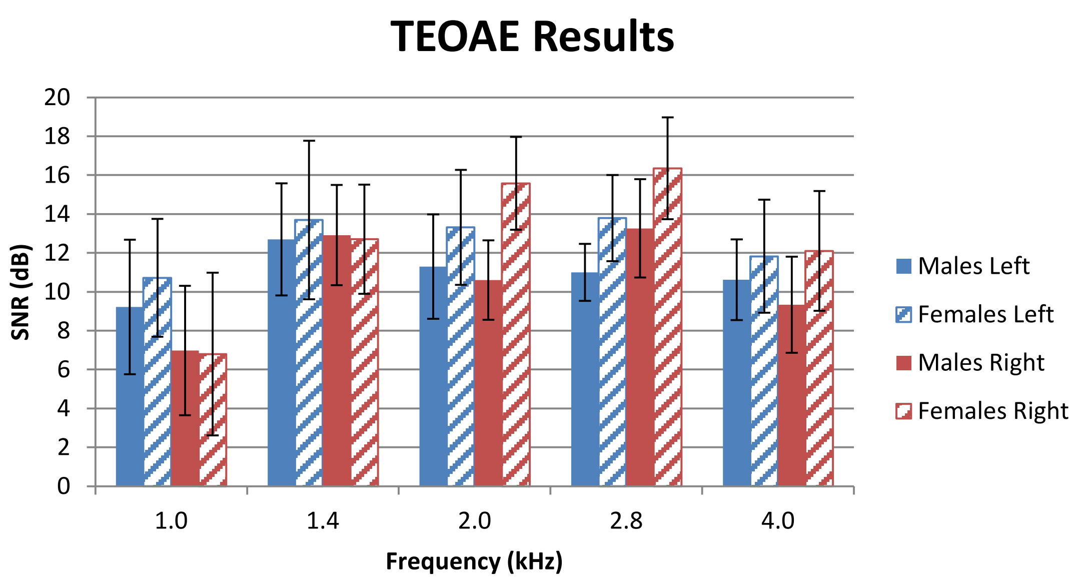

Figure 1. The mean signal-to-noise ratios for Transient Evoked Otoacoustic Emissions from 1000-4000 Hz for male and female left and right ears are displayed above. Standard deviations are depicted using the standard error bars. SNR = Signal to Noise Ratio. TEOAE = Transient Evoked Otoacoustic Emissions.

Table 5.

Transient Evoked Otoacoustic Emission Data

		SNR (dB)				
		1000 Hz	***1400 Hz***	***2000 Hz***	***2800 Hz***	***4000 Hz***
Males	***Right Ear***	6.98 (5.15)	12.92 (5.15)	10.6 (4.08)	13.26 (5.05)	9.33 (4.95)
	Left Ear	9.22 (6.91)	12.69 (5.76)	11.3 (5.37)	11 (2.92)	10.62 (4.16)
Females	***Right Ear***	6.79 (8.37)	12.71 (5.62)	15.8 (4.78)	16.36 (5.24)	12.1 (6.15)
	Left Ear	10.02 (6.06)	13.69 (8.17)	13.31 (5.92)	13.79 (4.44)	11.83 (5.82)

Note. The mean signal to noise ratios, measured in dB, of the transient evoked otoacoustic emissions data are displayed above according to gender and age group. The standard deviation values for each condition are contained in parentheses. All results are displayed according to the ear to which the stimulus was applied.

Additional Tests

A series of additional tests were administered in order to assess the language, attention, phonological, and intelligence abilities of the participants. The summary of the overall mean and standard deviation values for each test according to gender and age group can be seen in Table 6.

The participants' nonverbal intelligence was assessed using the TONI-3. Deviation quotient scores (scaled scores) were obtained and then converted to a percentage score as provided by the TONI-3 test manual. The quotient scores ranged from 100 to141 across all participants and the percentage scores ranged from 50 to 99%.

The language abilities of the participants were screened using the CELF-4 screening test. Raw scores were tabulated and compared to criterion scores based upon age. The raw scores ranged from 20 to 26, 21 to 30, and 22 to 30 for the 7-8, 9-10, and

Table 6.

Additional Test Performance

		7-8 Years		9-10 Years		11-12 Years	
		Males	***Females***	***Males***	***Females***	***Males***	***Females***
TONI	***Quotient***	114.8 (6.34)	114.4 (11.3)	121.2 (12.89)	109.8 (3.9)	106.33 (7.77)	106 (7.35)
	Percentage	82 (10.77)	78.2 (19.03)	86.8 (13.88)	73.8 (8.01)	65 (17.35)	63.75 (15.56)
CELF	***Criterion***	22.8 (2.17)	22.4 (2.07)	27 (3.54)	26.6 (1.52)	27.67 (4.04)	25.5 (3.87)
CTOPP	***Phonological Awareness***	113.2 (1.64)	115 (7.65)	109 (8.75)	108.4 (11.1)	112 (7.94)	107.5 (7.14)
	Phonological Memory	112.6 (8.32)	112.6 (8.59)	105.4 (10.9)	109.6 (6.84)	121 (3)	112.75 (5.68)
	Rapid Naming	115 (9.25)	115.6 (11.1)	113.2 (7.53)	120.4 (6.84)	107 (9.17)	116.5 (17.06)
IVA-CPT	***Auditory***	109.8 (19.7)	91 (30.62)	89.6 (18.6)	105.6 (13.7)	77.67 (32.32)	104.25 (14.43)
	Visual	109.4 (9.24)	105.6 (23.53)	91.2 (23.66)	97.6 (13.61)	104 (10.15)	101.75 (10.66)

Note. The mean test performance of males and females according to each age group are displayed above. The standard deviation values are contained in parentheses. TONI = Test of Nonverbal Intelligence – 3rd Edition. CELF = Clinical Evaluation of Language Fundamentals – 4th Edition. CTOPP = Comprehensive Test of Phonological Processing. IVA-CPT = Integrated Visual and Auditory Continuous Performance Test.

11-12 year old age groups respectively. All of these scores were at or above the criterion score relative to age, and therefore, all of the scores qualified as passing.

The CTOPP was administered as a test of the participants' phonological processing abilities. The composite scores that were recorded for each condition including phonological awareness, phonological memory, and rapid naming, are calculated based upon chronological age equivalents. The composite scores of the male participants ranged from 91 to 130 while the female scores ranged from 94 to 136. According to the CTOPP guide to interpretation, these scores are representative of the "average" (90-110), "above average" (111-120), "superior" (121-130), and "very superior" (131-165) categories.

Each participant completed the IVA-CPT as a measure of his or her sustained auditory and visual attention. Overall male auditory attention scores ranged from 42 to 128 and the male visual attention scores ranged from 51 to 125. The female group displayed auditory attention scores of 49 to 117 and visual attention scores of 79 to 135. A criterion level of sustained auditory and visual attention scores of 80 was used to quantify passing results. Overall, six participants presented with auditory attention scores below this level and two participants scored below this level for visual attention.

Statistical analysis.

Statistical analyses were performed on the additional test battery data and case history information using the IBM SPSS Statistics version 19. A bivariate correlation was performed to evaluate the relationship between the factors of nonverbal IQ scores, sustained auditory attention scores, handedness, and a musical instrument on the mean auditory processing test scores. The Pearson Product Moment Correlation coefficient was used to determine the strength of the relationship. An alpha value of 0.05 was used to determine significance.

Results of the bivariate correlation analysis used to evaluate the relationship between nonverbal IQ scores (as measured by the TONI quotient) and the mean auditory processing test performance revealed no significant findings or relationships. No significant findings were obtained for the correlation of sustained auditory attention scores (as measured by the IVA-CPT) and auditory processing test performance. Results of the bivariate correlation analyzing the relationship between handedness (as reported on the case history form) and the mean auditory processing test performance did not indicate significance. The correlation examining the condition of playing a musical instrument (as reported on the case history form) and mean auditory processing test performance showed significance for one test. A significant relationship was observed between the condition of playing a musical instrument (i.e. yes or no) and performance on the FPT, $r(25) = .41$, $p=.036$, suggesting that playing a musical instrument and FPT performance were strongly correlated.

Behavioral Auditory Processing Test Battery

In order to assess the auditory processing abilities of the participants, a test battery of seven tests was administered. The raw data was analyzed according to age and gender for each ear (when applicable). Descriptive statistic measures were performed using Microsoft Excel 2010. Mean and standard deviation values were calculated across each subgroup and displayed in chart form for visual representation. Additionally, the exact mean and standard deviation values for each APD assessment according to gender and age group can be seen in Table 7.

Table 7.

Auditory Processing Test Battery Performance

		7-8 Years		9-10 Years		11-12 Years	
		Males	***Females***	***Males***	***Females***	***Males***	***Females***
FPT	***Left Ear***	78.67 (.17)	81.33 (.14)	81.33 (.12)	94.67 (.06)	95.55 (.04)	86.67 (.05)
	Right Ear	80 (.17)	82.67 (.11)	84 (.11)	94.67 (.06)	93.33 (0)	95 (.1)
DPT	***Left Ear***	70.67 (.12)	77.27 (.08)	86.67 (.12)	88 (.13)	80 (0)	83.33 (.1)
	Right Ear	72 (.14)	74.6 (.03)	82.67 (.14)	94.67 (.09)	88.89 (.1)	88.33 (.1)
RGDT	***Binaural***	6.44 (2.51)	7.1 (2.5)	6.16 (3.17)	7.5 (2.34)	3.58 (.63)	7.01 (2.8)
DDT	***Left Ear***	93.5 (.04)	96.5 (.01)	95.5 (.05)	97.5 (.03)	99.17 (.01)	97.5 (.02)
	Right Ear	99 (.01)	96 (.03)	97 (.02)	99.5 (.01)	96.67 (.04)	98.75 (.01)
CRW	***Left Ear***	73.6 (.05)	71.2 (.04)	74.4 (.02)	74 (.03)	82 (.03)	80.5 (.03)
	Right Ear	70 (.06)	74 (.07)	76.4 (.02)	73.6 (.04)	80 (.03)	80 (.05)
AFG +8	***Left Ear***	89 (.05)	98 (.03)	95 (.04)	97 (.03)	95 (.09)	94 (.06)
	Right Ear	91 (.08)	96 (.04)	98 (.04)	92 (.03)	95 (.05)	99 (.03)
AFG 0	***Left Ear***	72 (.04)	78 (.04)	74 (.02)	72 (.04)	73 (.06)	76 (.03)
	Right Ear	71 (.07)	76 (.07)	80 (.04)	74 (.04)	73 (.03)	76 (.08)

Note. The mean auditory processing test battery performance of males and females according to each age group are displayed above. The standard deviation values are contained in parentheses. FPT = Frequency Pattern Test. DPT = Duration Pattern Test. RGDT = Random Gap Detection Test. DDT = Dichotic Digits Test. CRW = Compressed & Reverberated Words Test. AFG = Auditory Figure Ground.

Statistical analysis.

All statistical analyses were performed using the IBM SPSS Statistics version 19. One-way Analysis Of Variance (ANOVA) tests were performed to determine if the independent factors of age group (7-8 years versus 9-10 years versus 11-12 years), gender (male versus female), and ear (left versus right) had statistically significant effects on the dependent measure, the mean scores of each auditory processing assessment. An alpha level of 0.05 was used to determine significance. The p-values, F-values, and degrees of freedom (df) for each of the individual ANOVAs are contained in Table 8 for the monaurally administered tests and in Table 9 for the binaurally administered test. Significance will be reported in each individual test section.

A one-way between subjects ANOVA was conducted to compare the effect of gender (independent variable) on the mean scores of auditory processing tests (dependent variable) for the male and female conditions. Right ear and left ear scores were analyzed separately for the monaurally administered tests: FPT, DPT, DDT, CRW, AFG +8, and AFG 0 tests.

A one-way within subjects ANOVA was performed to examine if right versus left ear (independent variable) had a statistically significant effect on the mean performance scores (dependent variable). The mean test scores were entered as the dependent variable and ear (i.e., left or right) was entered as the factor (independent variable). This analysis was only calculated for tests that were administered in a monaural fashion.

In order to analyze the effect of age group (independent variable) on the mean auditory processing performance scores (dependent variable), a one-way between subjects ANOVA was calculated. If statistical significance was obtained, a series of independent sample t-tests were performed to identify which age groups had significantly different scores. The performance score was entered as the test variable (dependent variable) and the age groups were entered as the grouping variable (independent variable). For example, a t-test was used to compare the scores of 7-8 year olds to those of 9-10 year olds, 7-8 year olds to 11-12 year olds, and 9-10 year olds to 11-12 year olds. The t-test results are contained in Table 10. Right ear and left ear scores were analyzed separately for the monaurally administered tests: FPT, DPT, DDT, CRW, AFG +8, and AFG 0 tests.

Table 8.

One-Way ANOVA Results for Monaural Tests

		Gender		**Age**		**Ear**
		Left Ear	***Right Ear***	***Left Ear***	***Right Ear***	***N/A***
FPT	***p-Value***	0.40	0.20	0.17	0.07	0.56
	F-Value	0.74	1.75	1.89	3.05	.35
	df	1, 25	1, 25	2, 24	2, 24	1, 52
DPT	***p-Value***	0.27	0.27	0.03*	0.006*	0.74
	F-Value	1.28	1.28	3.95	6.41	0.11
	df	1, 25	1, 25	2, 24	2, 24	1, 52
DDT	***p-Value***	0.22	0.69	0.15	0.86	0.07
	F-Value	1.6	0.16	2.03	0.16	3.48
	df	1, 25	1, 25	2, 24	2, 24	1, 52
CRW	***p-Value***	0.61	0.73	0.00*	0.014*	0.92
	F-Value	0.27	0.12	14.74	5.13	0.01
	df	1, 25	1, 25	2, 24	2, 24	1, 52
AFG +8	***p-Value***	0.07	0.73	0.59	0.40	0.80
	F-Value	3.61	0.12	0.54	0.94	0.06
	df	1, 25	1, 25	2, 24	2, 24	1, 52
AFG 0	***p-Value***	0.35	0.88	0.58	0.42	0.35
	F-Value	0.92	0.03	0.56	0.91	0.88
	df	1, 25	1, 25	2, 24	2, 24	1, 52

Note. The statistical findings of the one-way ANOVA tests are displayed above for each of the monaurally administered assessments. The independent variables used were gender, age group, and ear. The one-way ANOVAs for gender and ear were performed for the left and right ear test conditions. ANOVA = Analysis of Variance. df=degrees of freedom. FPT=Frequency Pattern Test, DPT=Duration Pattern Test, CRW=Compressed & Reverberated Words test, AFG=Auditory Figure Ground.
*p< 0.05

Table 9.

One-Way ANOVA Results for Binaural Tests

			Gender	Ear
	RGDT	***p-Value***	0.12	0.55
		F- Value	2.59	0.61
		df	1, 25	2, 24
LiSN-S	**Low-Cue SRT**	***p-Value***	0.39	0.10
		F- Value	0.76	2.53
		df	1	2
	High-Cue SRT	***p-Value***	0.11	0.02*
		F- Value	2.72	4.79
		df	1	2
	Talker Adv.	***p-Value***	0.08	0.01*
		F- Value	3.46	6.30
		df	1	2
	Spatial Adv.	***p-Value***	0.60	0.20
		F- Value	0.29	1.73
		df	1	2
	Total Adv.	***p-Value***	0.03*	0.17
		F- Value	5.49	1.92
		df	1	2

Note. The statistical findings of the one-way ANOVA tests are displayed above for the two binaurally administered tests, the RGDT and the LiSN-S. The independent variables used were gender and age group. ANOVA = Analysis of Variance. df=degrees of freedom. RGDT=Random Gap Detection Test. LiSN-S=Listening in Spatialized Noise-Sentences Test.
*p< 0.05

Table 10.

Independent t-Test Results

	7-8 Years to 9-10 Years			9-10 Years to 11-12 Years			7-8 Years to 11-12 Years		
	p-value	***t***	***df***	***p-value***	***t***	***df***	***p-value***	***t***	***df***
DPT (Left Ear)	.016*	-2.66	18	.653	.458	15	.057	-2.07	15
DPT (Right Ear)	.007*	-3.05	18	.996	.005	15	.005*	-3.26	15
CRW (Left Ear)	.274	14.71	18	.000*	-5.29	15	.000*	-4.71	15
CRW (Right Ear)	.225	-1.26	18	.018*	-2.66	15	.013*	-2.8	15
LiSN-S High-Cue SRT	.086	1.82	18	.152	1.51	15	.012*	2.86	15
LiSN-S (Talker Advantage)	.838	-.21	18	.006*	-3.27	15	.001*	-4.34	15

Note. Results of the independent t-tests are displayed above. The t-tests were used to examine the differences between age groups on mean auditory processing scores on the tests which the ANOVA identified significance for age. ANOVA=Analysis of Variance. DPT=Duration Pattern Test. CRW= Compressed & Reverberated Words Test. LiSN-S=Listening in Spatialized Noise-Sentences Test. *p<.05

Tests of temporal processing.

The FPT was administered in order to evaluate the temporal processing abilities of the participants. Scores on the FPT were categorized according to right and left ear raw scores expressed as an overall percentage correct. Male right and left ear scores ranged from 60% to 100% with mean scores of 84.61% (0.13) and 83.59% (0.14) for the right and left ears respectively. The female ear scores also ranged from 60% to 100%, however, they had higher right and left ear mean scores of 90.48% (0.1) and 87.62% (0.11) when compared to the male group. Figure 2 below presents mean percentage scores and standard deviation values for the FPT according to age, gender, and ear. Statistical significance was not obtained for any condition of the FPT.

Figure 2.

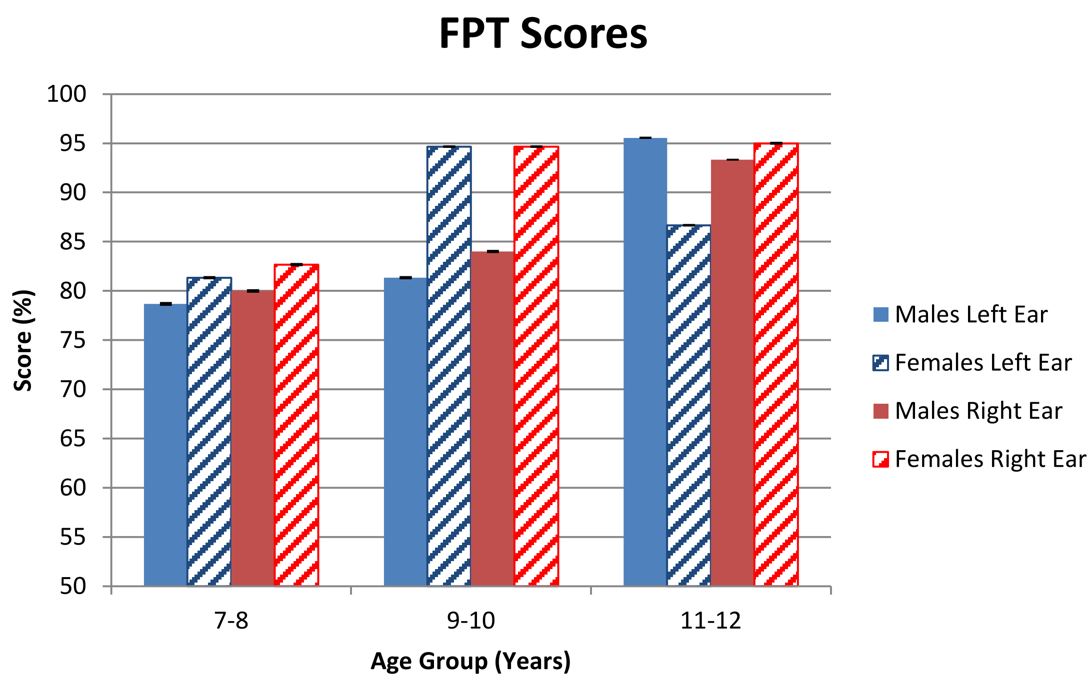

Figure 2. The mean percentage scores for the Frequency Pattern Test for male and female left and right ears are displayed above according to age group. Standard deviations are depicted using the standard error bars. FPT = Frequency Pattern Test.

The DPT assessed the temporal patterning abilities of the participants. Percentage correct scores were calculated for right and left ear performance on the DPT. Overall results ranged from 60% to 100% correct for the males and 66.67% to 100% correct for the females. The male group had mean right and left ear scores of 80% (0.14) and 78.97% (0.12) respectively, while the female group exhibited slightly higher average right and left ear scores of 85.69% (0.11) and 84.26% (0.12). The male and female mean percentage scores and standard deviations for the three age groups for the DPT assessment can be seen in Figure 3. Results of the ANOVA showed a statistically significant effect of age group on the left, F (2, 24) = 3.95, p=.033 and right, F (2, 24) = 6.41, p=.006 ear scores of the DPT. Because significant age effects were identified, a series of independent t-tests were performed to determine which age group comparisons were contributing. Results of a series of independent t-tests revealed a significant effect between the 7-8 year group and the 9-10 year group, t (18) = -3.05, p=.007, as well as between the 7-8 year group and the 11-12 year group, t (15) = -3.26, p=.005, for the right ear. For the left ear, significance was identified in the comparison of the 7-8 year and 9-10 year group, t (18) = -2.66, p=.016. Significant findings were not obtained for all other conditions.

Figure 3.

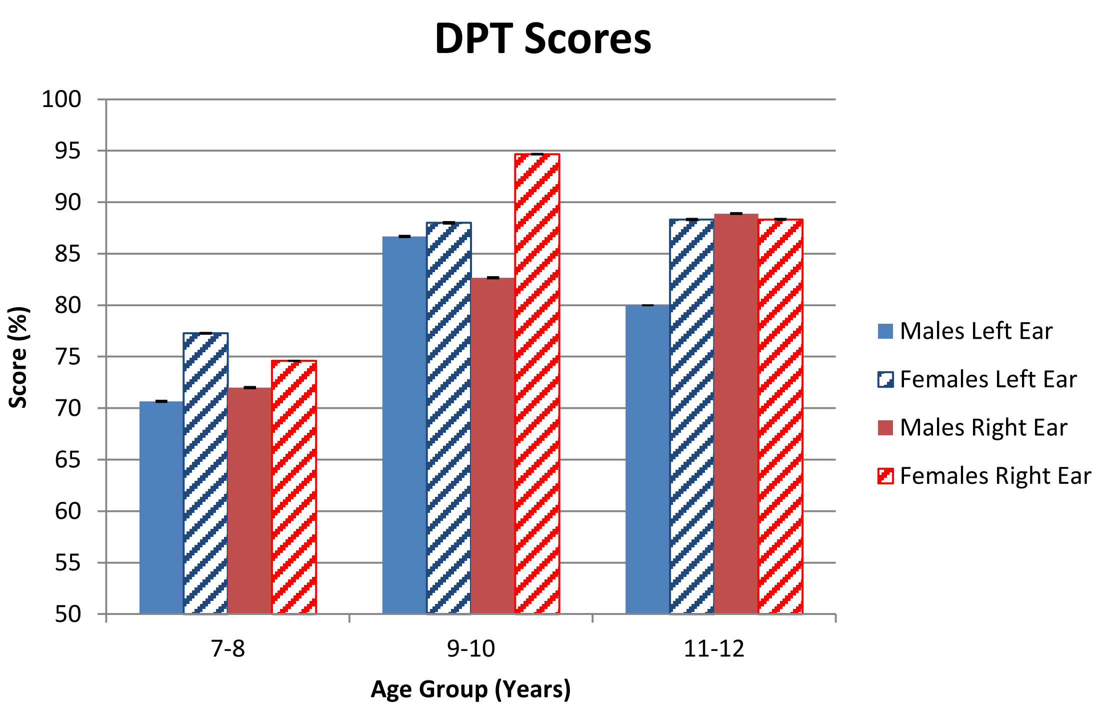

Figure 3. The mean percentage scores for the Duration Pattern Test for male and female left and right ears are displayed above according to age group. Standard deviations are depicted using the standard error bars. DPT = Duration Pattern Test.

The Random Gap Detection Test (RGDT) was used to assess the temporal resolution abilities of the participants. The male group had individual composite gap detection thresholds that ranged from 2 msec to 10 msec, with a mean composite gap detection threshold of 5.67 msec (2.64). The female participants' individual composite gap threshold levels ranged from 3.5 msec to 11.25 msec and exhibited a mean threshold level of 7.22 msec (2.34). The 11-12 year old male group had the lowest composite gap detection threshold with a mean threshold level of 3.58 msec (0.63). Overall, the male group had shorter mean gap detection threshold levels than the female group in each of the three age categories. Mean composite gap detection thresholds and standard deviations according to gender and age group, are displayed in Figure 4. Results of the ANOVA showed no statistical significance for age or gender.

Figure 4.

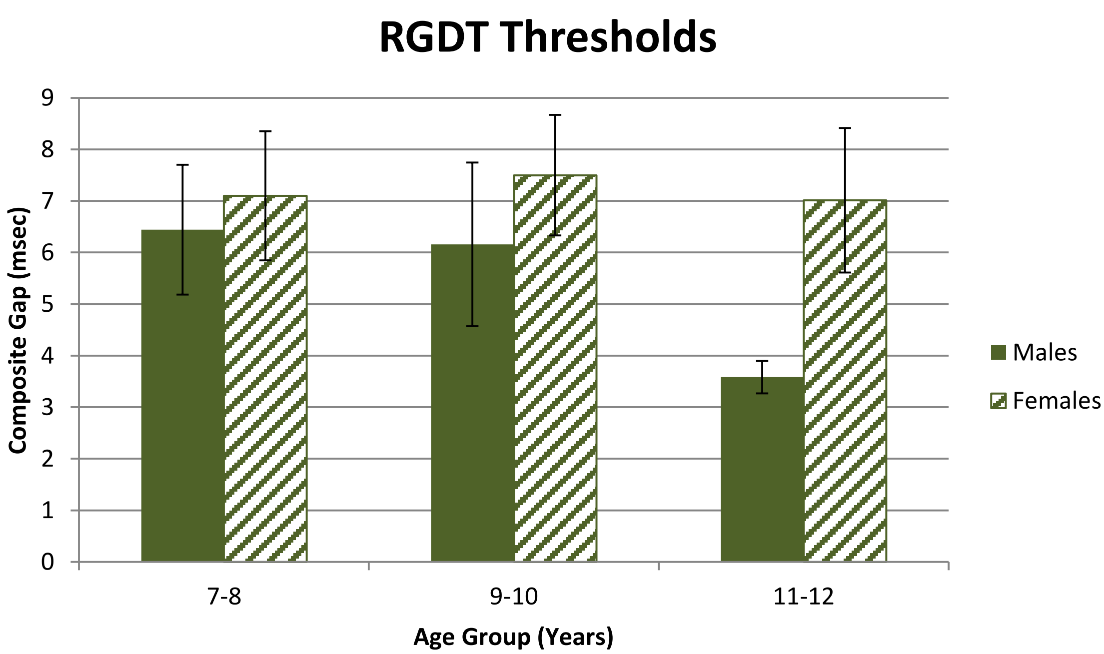

Figure 4. The mean composite gap detection threshold levels, measured in msec, for the Random Gap Detection Test for males and females are displayed above according to age group. Standard deviations are depicted using the standard error bars. RGDT = Random Gap Detection Test.

Test of dichotic listening.

The DDT was administered in order to evaluate the participants' dichotic listening abilities. The scores of the male participants ranged from 87.5% correct to 100% correct, with a mean score of 97.69% (0.02) and 95.58% (0.04) for the right and left ears respectively. The scores of the female participants ranged from 92.5% to 100% with right and left ear mean scores of 98.04% (0.03) and 97.14% (0.02). The mean right and left ear scores and standard deviations according to age and gender are displayed in Figure 5. Results of the ANOVA showed no statistical significance for age, gender, or ear.

Figure 5.

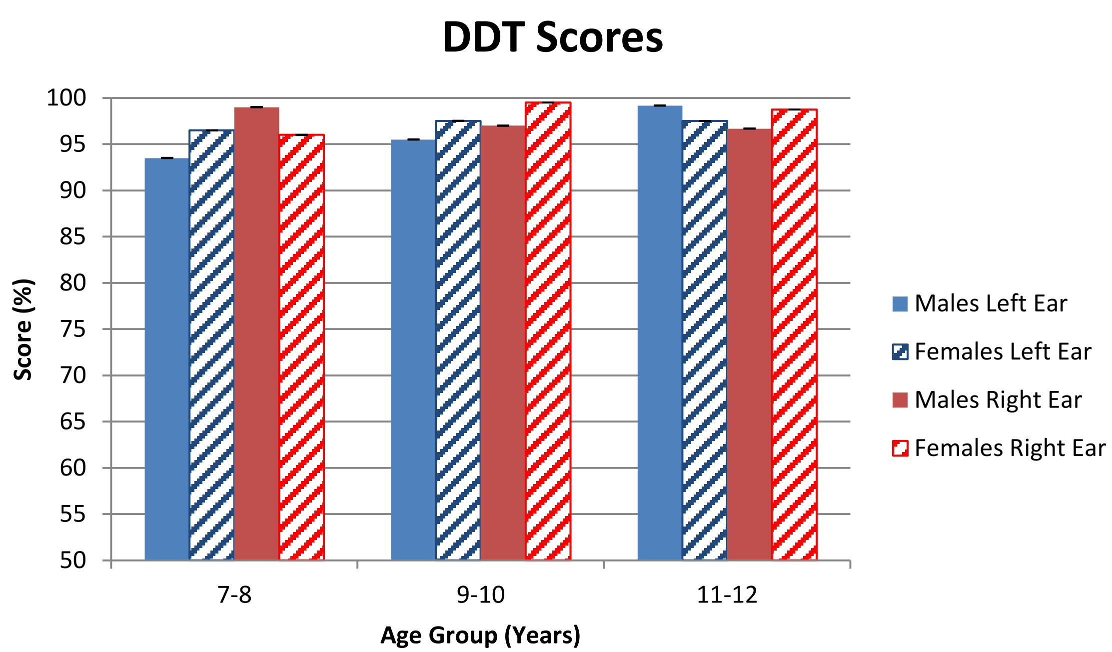

Figure 5. Mean percentage scores for the Dichotic Digits Test for male and female left and right ears are displayed above according to age group. Standard deviations are depicted using the standard error bars. DDT = Dichotic Digits Test.

Test of monaural low redundancy.

As a test of monaural low redundancy, the CRW test was performed and ear specific percentage correct scores were calculated. Overall performance between genders was similar, with a range of scores from 64% to 84% correct for the male group and 63% to 86% correct for the female group. Mean right and left ear scores for the male group were 74.77% (0.06) and 75.85% (0.05) for the right and left ears respectively and the female group ear scores were 75.57% (0.06) and 74.86% (0.05). Figure 6 contains mean scores and standard error values for the CRW test results according to ear, gender, and age group. Results of the ANOVA showed a statistically significant effect of age group on the left, $F(2, 24) = 14.74$, $p<.001$ and right ear scores of the CRW, $F(2, 24) = 5.13$, $p=.014$. Results of a series of independent t-tests revealed a significant difference between the 7-8 year group and the 11-12 year group, $t(15) = -2.8$, $p=.013$, as well as between the 9-10 year group and the 11-12 year group, $t(15) = -2.66$, $p=.018$, for the right ear. For the left ear, significance was identified in the comparison of the 7-8 year and 11-12 year group, $t(15) = -4.71$, $p<.001$, as well as between the 9-10 year group and the 11-12 year group, $t(15) = -5.23$, $p<.001$. Significant findings were not obtained for all other conditions.

Figure 6.

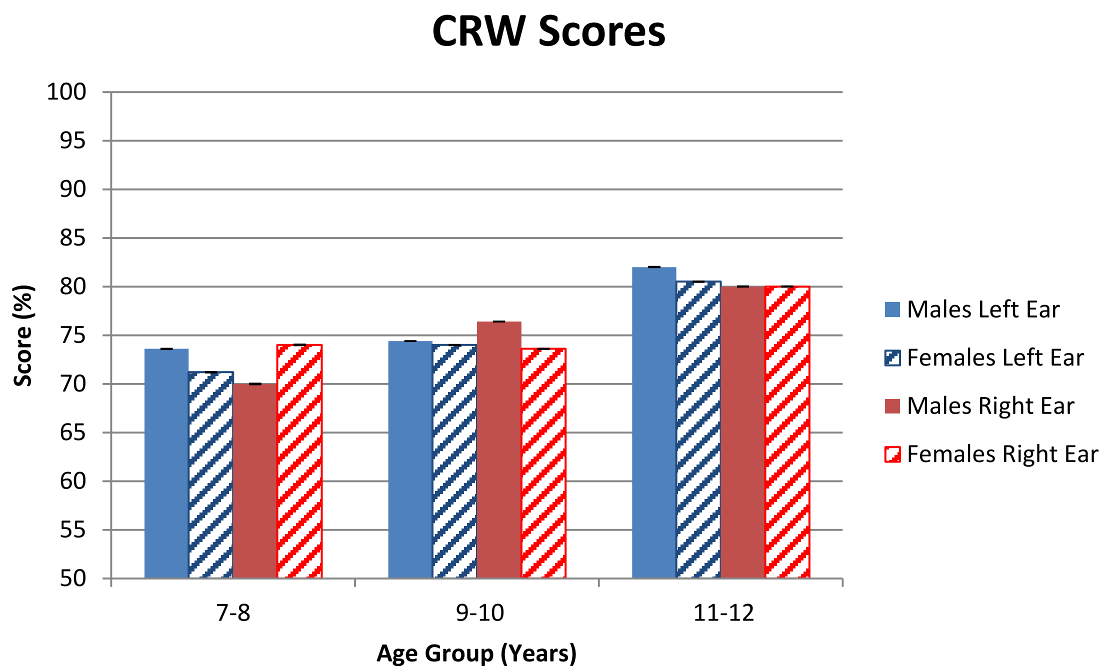

Figure 6. Mean percentage scores for the Compressed and Reverberated Words Test for male and female left and right ears are displayed above according to age group. Standard deviations are depicted using the standard error bars. CRW = Compressed and Reverberated Words Test.

The Auditory Figure Ground (AFG) test, a asubtest of the SCAN 3: C was administered in two conditions in order to assess the participants' abilities to understand speech in the presence of background noise. For the +8 dB test condition, the male group had mean ear scores of 18.92 (1.32) and 18.54 (1.2) for the right and left ears respectively, and the female group had mean scores of 19.07 (0.83) and 19.29 (0.82). The scaled scores ranged from 7 to 15, indicating that all participants scored in the normal range on this assessment. When converted to a percent score, the overall scores on this test ranged from 89% to 98% for the left ear and 91% to 99% for the right ear. Figure 7 displays the percentage scores and standard deviation values for each ear according to gender and age. Results of the ANOVA showed no statistical significance for age, gender, or ear.

Figure 7.

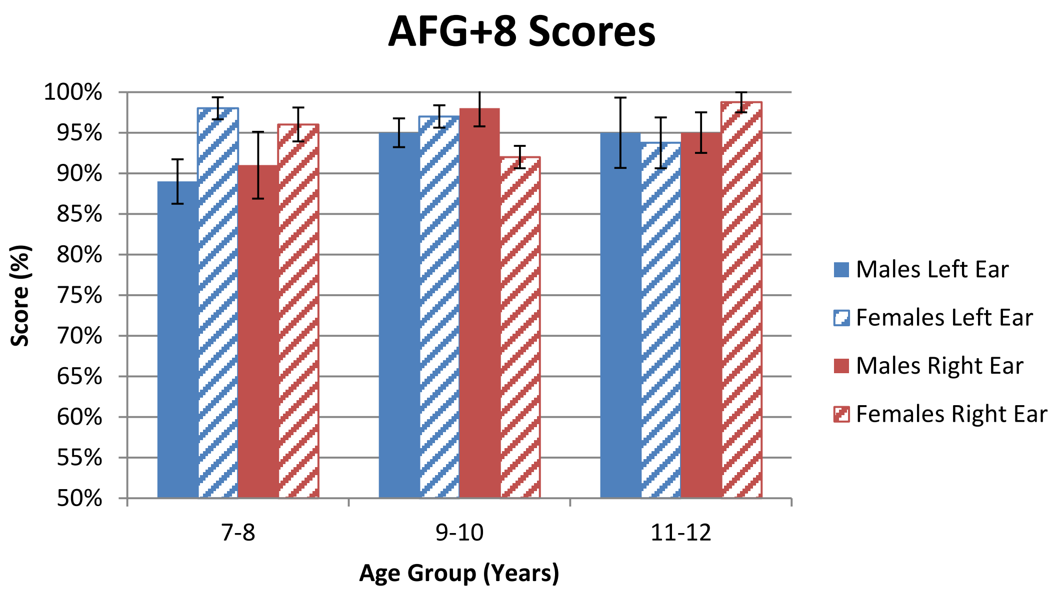

Figure 7. Mean percentage scores for the Auditory Figure Ground +8 subtest for male and female left and right ears are displayed above according to age group. Standard deviations are depicted using the standard error bars. AFG = Auditory Figure Ground. Note. AFG = Auditory Figure Ground.

For the AFG 0 dB test condition, the male group had mean right and left ear scores of 15 (1.22) and 14.61 (0.77), while the female group had mean scores of 15.07 (1.14) for the right ear and 15.07 (0.92) for the left ear. The scaled scores ranged from 8 to 14, signifying that all of the scores were once again within the normal range. The percent correct scores ranged from 72% to 78% for the left ear and 71% to 80% for the right ear across all participants. Mean percentage scores and standard deviations for the AFG 0 are contained in Figure 8. Results of the ANOVA showed no statistical significance for age, gender, or ear.

Figure 8.

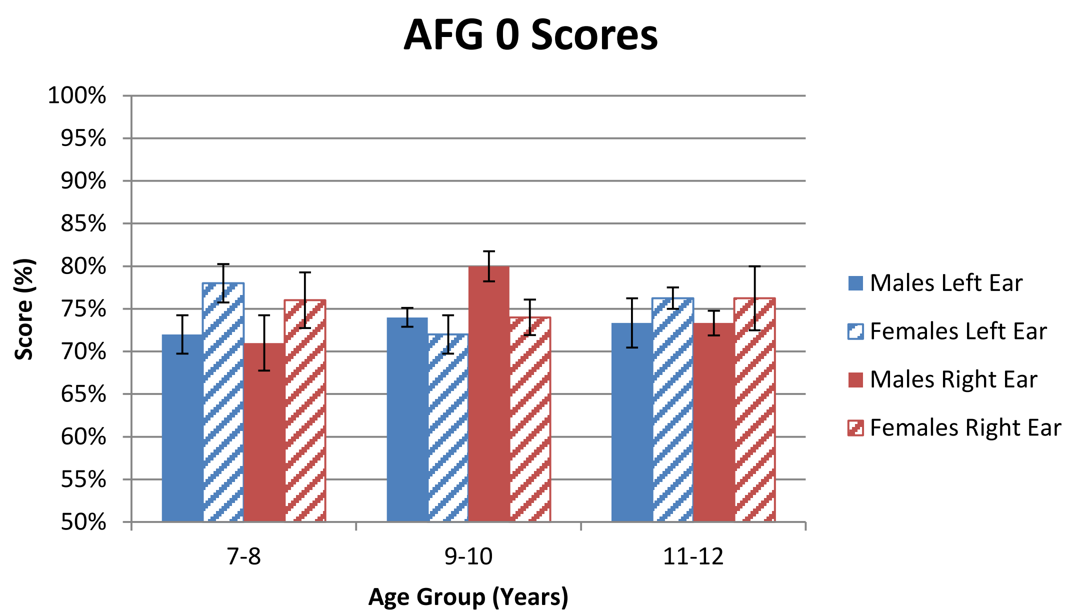

Figure 8. Mean percentage scores for the Auditory Figure Ground (0 dB) subtest for male and female left and right ears are displayed above according to age group. Standard deviations are depicted using the standard error bars. AFG = Auditory Figure Ground.

Test of auditory figure ground/localization.

In order to evaluate the participants' auditory stream segregation abilities, the Listening in Spatialized Noise (LiSN-S) test was performed in four different listening conditions. Test results identified a Low- and High-cue SRT and talker, spatial, and total advantage measures. Overall mean and standard deviation values were first calculated across all 27 participants. The mean and standard error values for all participants for each condition of the LiSN-S are contained visually in Figure 9 and numerically in Table 10. Results of the ANOVA showed a statistically significant effect of age group for the High-Cue SRT, $F(2, 24) = 4.79$, $p=.018$ and the talker advantage, $F(2, 24) = 6.30$, $p=.006$. Results of independent t-tests revealed a significant effect between the 7-8 year group and the 11-12 year group, t (15) = 2.86, p=.012, for the High-Cue SRT. For the talker advantage, significance was identified in the comparison of the 7-8 year and 11-12 year group, t (15) = -4.34, p=.001, and the 9-10 year and 11-12 year group, t (15) = -3.27, p=.006.

Figure 9.

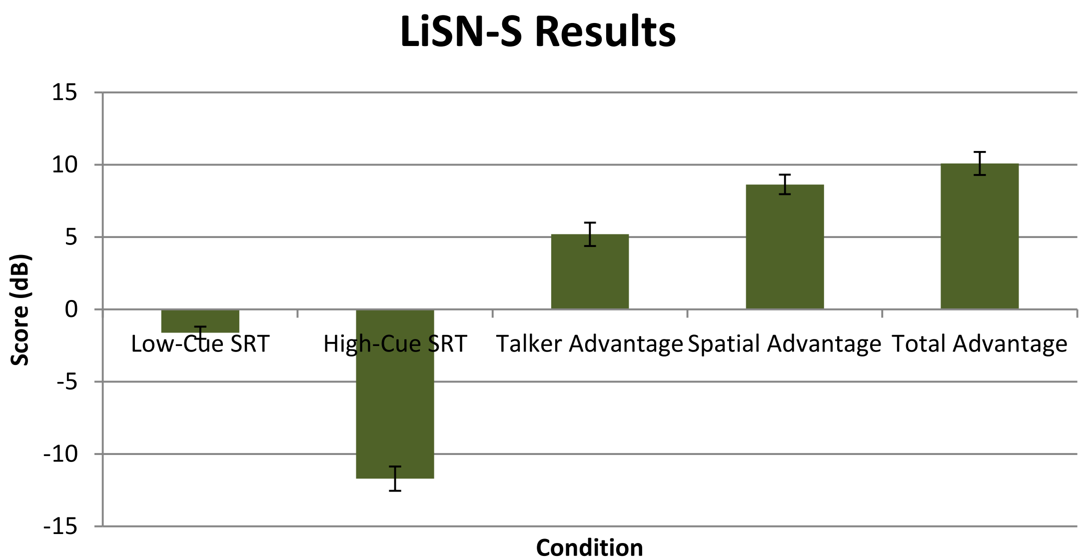

Figure 9. The mean scores for the Listening in Spatialized Noise-Sentences test for all participants, measured in dB, are displayed above according to condition. Standard deviations are depicted using the standard error bars. LiSN-S = Listening in Spatialized Noise-Sentences test.

In order to assess the differences observed between males and females, the SRT and advantage scores were calculated according to gender. Larger advantage scores were noted for females compared to males in all conditions. The mean scores and standard deviations for each condition according to gender can be seen in Figure 10. Detailed means and SDs can be seen in Table 11. Results of the one-way ANOVA revealed a significant effect of gender on the total advantage score, F (1, 25) = 5.49, p=.027.

Table 11.

LiSN-S Results

	Score (dB)				
	Low-Cue SRT	***High-Cue SRT***	***Talker Advantage***	***Spatial Advantage***	***Total Advantage***
Males	-1.78 (0.91)	-11.17 (2.0)	4.62 (1.8)	8.48 (1.62)	9.4 (1.8)
Females	-1.49 (0.78)	-12.21 (1.22)	5.71 (1.23)	8.76 (1.04)	10.72 (1.06)
All Participants (Total)	-1.63 (0.84)	-11.71 (1.70)	5.19 (1.6)	8.63 (1.33)	10.09 (1.59)

Note. The mean scores of the LiSN-S, measured in dB, for each condition are displayed above according to gender and to the overall performance of all participants. The standard deviation values are contained in parentheses. Note. LiSN-S = Listening in Spatialized Noise-Sentences Test.

Figure 10.

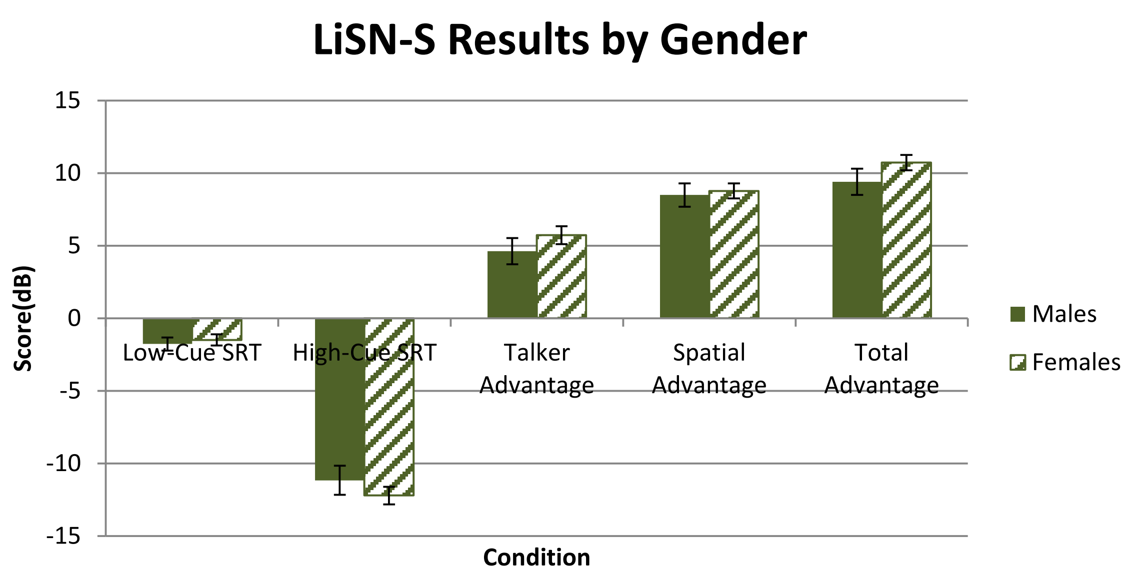

Figure 10. The mean scores for the Listening in Spatialized Noise-Sentences test, measured in dB, are displayed above for each gender according to condition. Standard deviations are depicted using the standard error bars. LiSN-S = Listening in Spatialized Noise-Sentences test.

CHAPTER 5

Discussion

Auditory processing disorder (APD), or inefficient processing of auditory stimuli not caused by a peripheral hearing loss that can be complicated by adverse listening environments, currently affects approximately 2-3% of school-aged children (ASHA, 2005; Chermak & Musiek, 1997; Jerger & Musiek, 2000; Witton, 2010). Individuals who have APD may experience difficulty localizing sound, understanding speech in the presence of background noise, and following verbal directions (AAA, 2010; Jerger & Musiek, 2000). These weaknesses may present challenges for listening and learning in the classroom setting.

The prevalence of many developmental disorders is higher among one gender than the other, with males typically being afflicted more often than females (Bamiou et al., 2001; Chermak et al., 1999; Sharma et al., 2009). Males have been documented as having an increased likelihood of exhibiting ADHD, autism, reading disorder, and SLI. Because the brain is complex and several of these disorders are often comorbid with others, it is necessary to examine if a gender bias exists within the APD domain (Witton, 2010).

The aim of this study was to investigate the auditory processing abilities of typically developing children between the ages of 7;0 and 12;11 years. A comprehensive test battery of sensitive and specific skills was administered to evaluate various aspects of auditory processing abilities. Additionally, a battery of additional tests was performed in order to evaluate language, phonological processing, sustained attention, and nonverbal IQ, as they may relate to auditory processing overall. Within this study, participants were gender balanced to investigate potential gender differences in auditory processing abilities. This study is part of a larger collective research project aimed at developing current, local normative data used for the diagnosis of APD.

Peripheral Auditory Sensitivity

The peripheral auditory sensitivity of all participants was screened in order to rule out peripheral hearing status loss as an influence on overall test performance. One participant in the study, an 11 year old male, was excluded from data analysis because of bilateral conductive hearing loss. On the case history form, the participant's mother indicated that he had a history of ear infections, as well as four sets of pressure equalization (P.E.) tubes. Further, she reported that he had a mild hearing loss prior to the P.E. tubes, but that it resolved following tube placement. Audiometric testing revealed a slight to mild conductive hearing loss with air-bone gaps averaging 20 dB from 250-4000 Hz bilaterally. Immittance findings revealed a Jerger A_D tympanogram for the right ear, with absent ipsilateral and contralateral ARTs for stimulation of the right ear from 500-2000 Hz. Due to the bilateral presence of a conductive hearing loss, no further testing was completed and the patient was excluded from the study.

For the remaining 27 participants who were included in data analysis, immittance testing revealed one participant with Type A_D tympanograms bilaterally and one participant with a Type A_D tympanogram and Type A tympanogram for the right and left ears respectively. A Type A_D tympanogram implies the presence of a hypermobile tympanic membrane, and is often indicative of scar tissue on the eardrum. Additionally, one participant had elevated or absent ARTs bilaterally for ipsilateral and contralateral conditions, but all other objective and subjective test results were within normal limits.

Although most individuals with normal hearing exhibit ARTs that are within normal limits, it has been shown that some people with normal hearing display absent or elevated thresholds therefore this participant was included in the data analysis (Gelfand & Piper, 1981; Gelfand & Piper, 1983).

Additional Test Performance

The IVA-CPT was administered as an assessment of the participants' sustained auditory and visual attention. Six participants' sustained auditory attention scores were below the standard cutoff score of 80. Additionally, two participants' visual scores were outside of the normative range. Throughout testing, none of these participants presented with abnormal attention abilities nor had any difficulty completing the test battery efficiently. Results of a bivariate correlation did not indicate a significant relationship between sustained auditory visual scores and overall test performance. For this reason, no participant was excluded from data analysis on account of his or her poor attention abilities as reflected by the IVA-CPT. It is important to examine sustained attention abilities, however, as it has been suggested that auditory processing abilities are largely related to attention (Moore et al., 2010).

The nonverbal IQ scores of participants, as indicated by the TONI-3 scores, were significantly higher than would be expected. All IQ scores were over 100, ranging as high as 141, and, as such, do not reflect a normal distribution. A bivariate correlation between the IQ scores on the overall test performance was not significant. This study was targeted towards typically developing children and the intent was to have children whose IQ scores more accurately resembled a normal distribution (i.e. scores ranging from 85-115). Therefore, this portion of the overall study may not be representative of average children and this factor should be considered when data are merged.

Similarly, the language skills and phonological processing abilities of all of the participants were in the normal to above normal range, based upon performance on the CELF-4 and CTOPP assessments. When comparing test performance to the associated normative criteria as provided by the assessments, all participants scored above the age matched cutoff score. Similar to the findings on the TONI, most scores were noticeably higher than the cutoff criteria, and performance was in the middle to upper range for all categories.

Auditory Processing Test Battery Performance

Age effect.

In order to examine the influence of maturation on the auditory processing abilities of the participants, the age effects of mean test performance were calculated. The auditory system continues to develop until approximately 12 years of age, so an increase in age is typically correlated with an increase in auditory processing abilities (Bellis, 2003). Following this reasoning, it was expected that mean test performance would be the lowest in the 7-8 year old group, and would improve for each the 9-10 year group and 11-12 year group.

On the auditory processing tests, significant age effects were identified on the DPT and the CRW tests. Performance on the DPT was characterized by a significant age effect for the left ear condition. Specifically, the mean performance of the youngest age group was significantly lower than that of both the middle and oldest age groups. Temporal patterning tasks require the right hemisphere for identification of pattern perception and the left hemisphere for verbal labeling, necessitating the use of the corpus callosum for the transfer or information (Bellis, 2003). The effect of age on the DPT results reflects the improved temporal patterning abilities of the older children that are associated with maturation of the corpus callosum (Bellis, 2003). Significant age effects were noted bilaterally for CRW performance between both the youngest and middle age groups compared to the oldest age group were identified.

On the LiSN-S test, the effect of age was statistically significant for the High-Cue SRT measure between the 9-10 year and 11-12 year groups. This measure takes into account all of the different conditions assessed throughout the test, and creates the advantage, in dB, that the participant receives when they have the most cues available (e.g., when sentence stimuli are presented at a spatially different location compared to background noise (i.e. +/- 90° versus 0°) and presented by a different voice than is being used as the speaker of the background noise). Similarly, a significant age effect was noted for the talker advantage. This specifically relates to the amount of benefit the participant received from the talker switching between a voice that was the same or different as the competing background noise. The talker advantage was significant for both the younger and middle age groups compared to the oldest age group, suggesting that with accompanying age, more benefit is received from talker cues or advantages.

Age effects were not observed for the FPT, DDT, RGDT, or either subtest of the AFG subtests of the SCAN 3:C. It is important to note that the mean and individual scores on all of these assessments were higher than would be expected based on current normative data, and an abnormal distribution of scores was present for the FPT and DDT specifically. One possible explanation is that the presence of ceiling effects could have limited the extent of the influence of age on performance. Neijenhuis, Snik, Priester, van Kordenoordt, & van der Broek (2002) observed similar findings regarding an absence of age effects on FPT performance, which they attributed to abnormal score distributions and unusual ceiling effects. For the most part, temporal patterning abilities increase with neuro-maturation of the corpus callosum (Bellis, 2003), and are typically adult-like by the age of 11 to 12 years. As such, a significant age effect would be expected on tasks of this nature, including both the DPT and FPT.

Additionally, age effects are typically seen on dichotic listening tasks such as the DDT. Neijenhuis et al. (2002) found that significant performance differences can exist for children between the ages of 9 through 12 years, with a further increase in abilities noted through adolescence for the DDT. The extent of the right ear advantage (REA) usually diminishes with increasing age, as left ear performance improves (Bellis, 2003; Moncrieff, 2011).

Generally, the differences on the RGDT observed between age groups are typically minimal, if evident at all. The normative criterion for this test is 20 msec for subjects of all ages, including both children and adults. Within this study, no formal or informal age effects were observed for composite threshold data. A study of RGDT performance by Keith (2000b) reported similar gap detection thresholds for 5-7 year old subjects and 10-11 year old subjects. Similarly, a normative study by Kelly (2007) did not observe significant age effect for RGDT results. Therefore, the maturational effects of temporal resolution abilities are typically complete by age 7, and the insignificant age effect observed in this study is consistent with the current literature. Thus, the current study was consistent with prior studies indicating that the overall normative criteria should be lowered (Kelly, 2007).

Ear effect.

It is theorized that when competing stimuli are presented dichotically, the contralateral neural pathways are dominant, so information presented to the right ear is first processed by the left hemisphere, and vice versa (Bellis, 2003; Kimura, 1961). Because the left hemisphere is usually the language dominant hemisphere, stimuli presented to the right ear are processed by the left hemisphere via the contralateral pathways. Stimuli presented to the left ear, however, travel first to the right hemisphere, then cross the corpus callosum, and are then transferred to the left hemisphere for processing. Additionally, the corpus callosum is not fully matured until adolescence and can result in an even more delayed transmission time for stimuli presented to the left ear (Bamiou et al., 2001; Bellis, 2003). For this reason, a REA is typically observed on dichotic listening tasks, in which higher performance scores are noted for the right ear versus left ear conditions. It has shown in the literature that for more complex stimuli, left ear performance improves and the REA reduces over time with increasing age and maturation (AAA, 2010; Bellis, 2003).

No significant findings were obtained for the effect of ear (left versus right) on auditory processing test performance. These results were unexpected, as there is a well-documented REA that is typically observed on the DDT (Bellis, 2003; Neijenhuis et al., 2002). Although statistical significance was not identified using a one-way ANOVA, noticeable trends between right and left ear performance were observed upon examination of individual scores. Specifically, right ear performance was higher than left ear performance for 70% of the participants in the 7-8 year age group, with the noted REAs ranging from 2.5% to as much as 10%. Examination of performance scores for the 9-10 year age group revealed that only 50% of the participants displayed a REA. The noted REAs in this age group were not as large, with most of them documenting only a 2.5% advantage for right ear performance versus left ear performance. For the oldest age group, only two participants presented with a REA, with the noted effects being only 2.5% and 5%. The remaining participants who did not display a REA, exhibited either a left ear advantage (LEA), or no ear advantage (NEA) at all.

The overall trends seen in the current data are consistent with the literature, and showed a decreasing REA in association with increased age. Well documented REA on the DDT were observed by Neijenhuis et al. (2002), with a reported mean advantage score of 10% that was stable in child, adolescent, and adult subjects. In contrast, Moncrieff and Musiek (2002) reported that the effects of ear show wide variability when the DDT is administered in the free recall condition, as it was in this study. The reduction of the REA seen with the increasing age groups is expected based upon the low linguistic loading of the DDT assessment.

Although the REA is well documented in the literature, Moncrieff (2011) recently reported that only 80-85% of children exhibited this right ear dominance. They found that 10-15% of children presented with a left ear advantage (LEA) or no ear advantage (NEA) on tests of dichotic listening (Moncrieff, 2011). Therefore, although a majority of children exhibit a REA, evidence suggests that all typically developing children may not present with it.

Gender effect.

When considering the potential influence of gender on LiSN-S test performance, larger advantage scores were recorded for females than males in all test conditions (i.e. talker advantage, spatial advantage, and total advantage). The total advantage scores were found to be significantly different between genders, with the females exhibiting higher overall advantages. This potential gender effect on auditory stream segregation and localization abilities has not been documented in the literature.

No other significant findings were obtained regarding male versus female performance on the auditory processing test battery, however, noticeable trends were observed on some of the tests. For the DPT, the females outperformed the males bilaterally in both the 7-8 year group and 9-10 year group. On the RGDT, the mean gap detection thresholds were consistently lower for the male participants across all three age groups.

Recently, Moncrieff (2011) observed a significant effect of gender on ear advantage scores on dichotic listening tasks for children from 5 to 12 years of age. The overall mean average REA scores were greater among male participants than female participants on the Randomized Dichotic Digits Test (RDDT) (Moncrieff, 2011). More research is needed to further investigate the effect of gender on ear advantages and overall auditory processing abilities.

Additional findings for APD battery.

The results of the test of temporal resolution, the RGDT, revealed composite gap detection thresholds that are significantly better than would be expected based upon nationally published normative data. Currently, a normative cutoff score of 20 msec is used for all participants, regardless of age. In this study, overall mean thresholds were 5.67 msec for the males and 7.22 msec for the females, and when accounting for two standard deviations, the values are still well below the 20 msec criterion. When considering individual performance on the RGDT, the highest identified composite threshold was 11.25 msec. The mean gap detection thresholds identified in this study are similar to those reported by Chermak and Lee (2005) who observed a mean gap detection threshold of 4.77 (1.83) msec for children with normal hearing between the ages of 7 and 11 years. Because typically developing children are exhibiting low composite gap thresholds, it is proposed that the currently accepted 20 msec cutoff may not be stringent enough to identify abnormal temporal resolution abilities.

Performance on the CRW test was more variable than performance on the other assessments in the test battery. Scores on this test ranged from 64% to 84% correct, indicating that every participant missed at least eight test items per ear. As part of a previous related research study, 25 test items were administered per ear, but the test items were increased to 50 for this study due to reported variability. Several noticeable trends were also apparent during test administration. For example, for the test item “sale,” a commonly provided incorrect answer was “sailor.” Also, administering 50 test items per ear was time intensive and it was difficult to keep the participants’ attention for the entire task. Consideration should be given to revising this test and/or finding a better measure of monaural low redundancy to incorporate in the behavioral test battery.

The AFG subtests aimed to further investigate monaural low redundancy abilities, however, no significant findings or trends were obtained. No significant age, gender, or ear effects were identified on the AFG subtests. Although increasing performance is expected as a result of increasing age, the AFG test stimuli are simple and statistically insignificant effects for normal children are not unexpected.

Confounding Factors

Prior to inclusion in the study, screening questions were asked and the additional test battery was administered in an attempt to ensure that all participants were typically developing. Although these screening questions were administered, the possible interference of other confounding factors on overall test performance cannot be ruled out. It is important to acknowledge and recognize these potential interferences and examine their effect or relationship on the test results.

Case history.

The importance of a thorough case history has been stressed in the literature, and an extensive case history form was used to identify any potential red flags in each participant's history and/or current functioning (AAA, 2010). The influence of middle ear status on overall auditory sensitivity is well known. For those included in data analysis, 15 of the 27 participants have an otologic history that is significant for ear infections. Furthermore, two of the children included in data collection have had P.E. tubes. Tympanometric data for both of these participants was within the normal range, suggesting that the ear infections and P.E. tubes did not leave lasting effects on the tympanic membrane and/or middle ear. The potential influence of middle ear status, specifically otitis media with effusion (OME), has been evidenced by Moore, Hartley and Hogan (2003). These findings revealed that those with a history significant for recurrent OME display reduced binaural hearing abilities and, if severe, temporal hearing abilities (Moore et al., 2003). The impaired auditory processing abilities are typically temporary and reversible, but they should not be disregarded. For this reason, the fact that 56% of the participants had a significant middle ear history should not be ignored and presents itself as a possible factor in the overall findings and test performance.

The influence of other variables such as handedness and a positive or negative history for playing a musical instrument on overall test performance was examined. Six of the participants were left hand dominant, while the remaining 21 were right handed. The hand dominance of subjects was not significantly related to APD test performance. This finding is consistent with studies by Moncrieff (2011) and Moncrieff and Musiek (2002) who, similarly, did not find an effect between handedness and auditory processing performance.

As indicated on the case history forms, a majority of the participants had experience with playing a musical instrument (67%). Of note, a significant relationship was found between playing a musical instrument and overall performance on the FPT. Specifically, a positive history for experience with a musical instrument was related to increased performance on the FPT, suggesting stronger temporal processing abilities. Conversely, a history that is not significant for playing a musical instrument is correlated with decreased performance on the FPT. This finding is not surprising because those who play a musical instrument are typically attuned to harmony and pitch recognition (Ono et al., 2011). Additionally, the recommendation of playing a musical instrument is often made to individuals with temporal processing deficits, as a way to enhance their overall pitch and tonal recognition abilities.

Length of the test battery.

A second confounding factor in the overall study findings is the length of the test battery. On average, the test sessions were between four and five hours in length. Participants were urged to separate the testing into two days whenever possible, but most sessions were completed in one day for scheduling and convenience purposes. Depending on the speed at which the participants could complete the test battery, some were able to complete the test battery quicker than others. Overall, the test session was time intensive and the participants' attention waned markedly over time. Additionally, there was a noticeable difference in the ability of the older participants to sustain attention throughout the test battery compared to the younger participants. All participants were given several breaks throughout testing, and additional breaks were provided on an as-needed basis. Also of note is that test sessions were scheduled at all different times of day depending on the availability of the participants. As such, some test sessions were completed early in the morning when the participants were refreshed and well rested, while others were scheduled in the late afternoon and early into the evening, after the children had had long days prior to testing. The length of the test battery in this study exceeds the recommendation of AAA (2010), which state that no more than 45-60 minutes worth of behavioral testing should be completed in one session.

Motivation.

The motivation of each individual participant should not be ignored as a variable in test performance. The positive effects of motivation and reinforcement during APD assessments have been evidenced by Silman, Silverman, Emmer (2000). Their study noted marked improvement in auditory processing performance scores for conditions in which reinforcement was provided as compared to a non-reinforcement condition. It was concluded that observed reduced test performance was not due to an actual APD, but rather attributable to a lack of motivation (Silman et al., 2000).

As a source of motivation in this study, all participants were reimbursed monetarily for their involvement and participation in the research study. This incentive was presented to them prior to beginning the test session and all participants were aware that they needed to complete the test battery accurately and reliably in order to receive the reimbursement. Additionally, an effort was made to recruit participants in pairs, so that each participant had moral support from a friend or sibling throughout the test session. When possible, the participants were given breaks at the same time and were motivated to be efficient during testing in order to be given a break with their friend. Positive reinforcement was provided throughout testing in order to motivate the participants and keep them actively engaged in the testing. Further, the participants were allowed to make decisions of their own throughout the test session, for example, picking which ear they would like to begin with on a certain assessment. Even with these incentives and attempts to motivate the participants as much as possible, the inherent level of motivation varied significantly from child to child. There is no way to rule out the potential side effects of those who did not seem to be actively engaged or to feel any sense of drive to complete the test battery to the best of their ability.

Study Limitations

Sample size.

This study targeted to recruit and collect data on 30 typically developing children from within the greater Baltimore area. Following data collection and elimination of one participant, the final data analysis was completed on 27 children. Because this study was aimed at investigating the potential influence of both gender and age on auditory processing abilities, the participants were divided into small groups that were age and gender matched. After the groups were established, the sample size within each group was typically only five participants (when age bands were divided into genders). In the 11-12 year old group, there were only four females and three males. With a sample as small as this, it is difficult to generalize the findings to the population at large. It is important to note, however, that the significant results that were obtained using a small sample size are likely representative of a powerful effect. Although the data reported here are based upon a small sample size, however, this is only one quarter of a larger scale research study. Therefore, before the data is completely synthesized, the sample size will be much larger, with approximately 120 participants.

Recruitment.

It is important to report that recruitment for participation in this research study was difficult. Large scale recruitment efforts through the local school systems were made, but yielded very little return. Additionally, several people who expressed interest in participating in the study were excluded due to the presence of other speech and/or developmental disorders, for which they did not qualify based on the exclusionary criteria of the study. For this reason, most of the participants were recruited by word of mouth and were referred to the study by the families of previous participants. When interested families of potential participants contacted the research study for information, it was encouraged that they contact a friend or relative to bring to the test session, as well. By doing so, two participants were often recruited off of only one contact. The negative to this is that both children were typically from the same background. As a result of these recruitment issues, the study participants were from similar upbringings and circumstances, and the majority of children were from high socio-economic status (SES) families. At large, the participants represented a very limited population from the local area, and were reflective of the higher SES community.

IQ scores.

The homogeneity of the sample overall was additionally reflected in the participants' IQ scores as measured by the TONI. As reported earlier, the IQ scores ranged from 100-141, indicative of an above average distribution. The associated percentages that are reported with the quotient scores ranged from the 50^{th} to the 99^{th} percentile, with a mean of 76%, further representing the higher than usual IQ scores. This elevation in IQ scores is not unexpected given that most of the participants were selected from high SES communities, however, it is important to bear in mind that these scores are not reflective of the general population. Although the results of the statistical analysis did not reveal a significant relationship between IQ scores and the mean auditory processing test performance, it is possible that there is not a large enough range of IQ scores to properly assess for such a relationship. Specifically, there was very little variety in both the IQ scores and the auditory processing scores, and ceiling effects may have prevented the potential for a significant relationship to be present.

Abnormal score distributions.

For each auditory processing test in the battery, the standard deviation values were calculated in order to examine the overall performance distribution and the spread of scores around the mean. For the majority of the tests, the standard deviation values were minimal. Specifically, the mean scores on the FPT, DPT, DDT, and CRW were tightly gathered around the mean value and displayed minimal variation in either the positive and negative directions. These findings were not expected, and may reflect the performance of participants who exhibited very high IQ scores. Overall, the mean test performance was higher than nationally published normative data, as provided by Bellis (2003). The consistency in scores within each age and gender group, and among the participants overall, makes it difficult to analyze these findings for statistical significance because of issues related to normality. The homogenous nature of this sample is potentially related to the overall test performance, and may explain the lack of standard deviation for these test measures. The small standard error values represent a major limitation of this study, because when there is little variation from the mean, it is difficult to identify what is an acceptable range of normal.

Clinical Relevance

Based on the findings of this study, the inclusion of additional tests to examine language, attention, and phonological processing abilities, as used in this stud, is recommended for both clinical and research populations. It is important to recognize the influence of these potential factors (i.e., attention, phonological processing, and nonverbal intelligence) in overall test performance. Clinically, any weaknesses that are identified prior to testing may be accounted for by selecting an appropriate test battery that limits the confounding influence of the observed weaknesses as much as possible. The identification of weaknesses may also allow for more appropriately tailored follow-up recommendations. For the purposes of research, these test measures allow the researcher to have an accurate understanding of the participant's abilities.

The behavioral test battery data obtained in this study represents normative test performance among the local population. The findings can be applied to the development of larger scale normative data, but strict cutoff values should be interpreted with caution based upon the largely abnormal score distribution and small standard deviation values.

The most apparent finding on the behavioral portion of this research study was the performance on the RGDT in reference to widely used normative data. Currently, a composite gap detection threshold of 20 msec or less is considered to be indicative of normal. Results of this study would suggest that the range of normal is much lower than 20 msec. The mean composite gap detection threshold overall was approximately 6.5 (2.5) msec, so using a range of two standard deviations, the normal range would be 1.5 to 11.5 msec. Therefore, using a cutoff value of 15 msec to quantify normal would be appropriate, yet still cautious, for use in the clinical population.

Future Directions

For appropriate and accurate diagnosis of APD, it is important the apply normative data that is appropriate for the population being tested (AAA, 2010; Bellis, 2003). This research study represents one-fourth of a large scale study designed to collect normative data for use in the Baltimore area. Following data collection and initial data analysis, the data from the four respective studies will be compiled and re-analyzed. Normative data on the core battery of auditory processing assessments used in this study will be established. The establishment of normative data for use with other populations is recommended using a study protocol similar to the one described with this study.

This study investigated the potential influence of gender on auditory processing test performance. No significant findings were obtained between the performance of male and female participants, however, future research should be dedicated to further examining the possible gender differences. Extensive previous research has documented the higher male prevalence for many developmental disorders, and larger scale research should hence examine the possibility of this trend continuing to the APD arena.

APPENDIX A

TOWSON UNIVERSITY

Date: Wednesday, January 27, 2010

NOTICE OF APPROVAL

TO: Jennifer Smart **DEPT:** ASLD

PROJECT TITLE: *Auditory Processing Abilities in Typically Developing School-Aged Children*

SPONSORING AGENCY:

APPROVAL NUMBER: 10-A035

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

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

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

This protocol was first approved on: 27-Jan-2010
This research will be reviewed every year from the date of first approval.

Justin Buckingham
Justin Buckingham
Towson University Institutional Review Board
WRP

TOWSON UNIVERSITY

APPROVAL NUMBER: 10-A035

To: Jennifer Smart
8000 York Road
Towson MD 21252

From: Institutional Review Board for the Proctection of Human Subjects Justin Buckingham

Date: Wednesday, January 27, 2010

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

APPROVED JAN 27 2010 JB/wp TOWSON IRB

Office of University
Research Services
Towson University
8000 York Road
n, MD 21252-0001
t. 410 704-2236
f. 410 704-4494

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

Auditory Processing Abilities in Typically Developing School-Aged Children

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

CC: L.Dau, T. Colon, E. Daniel
File

APPENDIX B

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): ____?

	Yes	No	Age(s)
Tonsillectomy?	_____	_____	______
Adenoidectomy?	_____	_____	______

APPENDIX C

TOWSON UNIVERSITY

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

INFORMED CONSENT FORM

Project title: Assessing Auditory Processing Abilities in Typically Developing School-Aged Children

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

Purpose of the Study:

Children who have difficulty with auditory processing sometimes have problems with language tasks such as following spoken instructions and understanding speech in difficult listening situations (e.g., a noisy classroom), even when they have good hearing and intelligence. The purpose of this project is to obtain local normative data for several routine tests of auditory processing.

Procedures:

If your child participates in this study, a series of assessments will be performed. This will involve two sessions lasting a total of approximately four hours. During these sessions your child will participate in a number of different listening, learning and language tasks. For some tasks your child will be asked to report back what they hear through earphones. Short breaks will be provided as needed during testing to avoid fatigue. These sessions will take place at Towson University Speech-Language and Hearing Clinics (TUSLHC) or in Dr. Smart's research laboratory. Children usually enjoy the variety of listening games and activities so we anticipate that they will be excited about this study. But if, at any time, your child decides he/she does not want to participate the testing will cease immediately.

Risks/Discomfort:

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

Benefits:

Currently there are no local norms for many of the currently available tests of auditory processing; therefore, the goal is to obtain this information. The data collected during this research study will not only be used to assist in the identification of children with auditory processing disorder but it will also be used to support future research studies at the university when normative data is required.

Participation:

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

Compensation:

All participants of this study will receive a $30.00 gift card upon completion of the study.

Confidentiality:

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

- -

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

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

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

_____ Affirmative agreement of child

____ ______________
Parent/Guardian's signature Date

Home address: ____

____

____

Home phone number: _____________________________________

Email address: ____

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

____________________________________ ______________
Principal Investigator's Signature Date

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

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

APPENDIX D

TOWSON UNIVERSITY

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

INFORMED ASSENT FORM

Project title: Assessing Auditory Processing Abilities in Typically Developing School-Aged Children

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

Information Sheet for Participants

(To be read aloud to each participant)

Purpose of study

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

What tests does the study involve?

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

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

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

Visits

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

Child Assent Form

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

Title of Project: Auditory Processing Abilities in Typically Developing School-Aged Children

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

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

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

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

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

Today's date:…………………………………

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

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

APPENDIX E

Participants needed for Auditory Processing Research

Does your child have normal hearing and normal speech, language, learning, and reading abilities?

If so, please consider participating in this research project!

Why?

To gather normative data for tests of auditory processing that are routinely used in the clinical environment. The data collected in this study will provide much needed data for both the clinical assessment of auditory processing disorder (APD) and for future research studies in the area of APD requiring normative data.

What is auditory processing?

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

Where?

All testing will be conducted at the *Towson University Speech, Language & Hearing Center* located on Towson University's campus in Van Bokkelen Hall and in Dr. Smart's laboratory.

When?

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

Who?

We are looking for typically developing children (males and females) ages 7—12 with no history of learning, language, reading, or hearing difficulties.

Interested in learning more?

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

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

References

American Academy of Audiology (2010). Diagnosis, Treatment and Management of Children and Adults with Central Auditory Processing Disorder [Clinical Practice Guidelines].

American Psychiatric Association (1994). *Diagnostic and statistical manual of mental disorders IV*. Washington D.C.: American Psychiatric Association.

American Speech-Language-Hearing Association (ASHA). (2005). (Central) Auditory Processing Disorders [Technical Report].

American Speech-Language-Hearing Association (2006). Central auditory processing: Current status of research and implications for clinical practice. *American Journal of Audiology, 5*, 41-54.

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

Bauermeister, J.J., Shrout, P.E., Chavez, L., Rubio-Stipec, M., Ramirez, R., Padilla, L.,…Canino, G. (2007). ADHD and gender: are risks and sequela of ADHD the same for boys and girls? *Journal of Child Psychology and Psychiatry, 48*(8), 831-839.

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

Bellis, T.J., Nicol, T, & Kraus, N. (2000). Aging Affects Hemispheric Asymmetry in the Neural Representation of Speech Sounds. *The Journal of Neuroscience, 20*(2), 791-797.

Bellis, T.J., & Wilber, L.A. (2001). Effects of Aging and Gender on Interhemispheric Function. *Journal of Speech, Language, and Hearing Research, 44,* 246-263.

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,* 31-42.

Brown, L., Sherbenou, R. J., & Johnson, S. K. (1997). *Test of Non-Verbal Intelligence-Third Edition, Examiner's Manual*. Austin, TX: PRO-ED.

Cameron, S., Brown, D., Keith, R., Martin, J., Watson, C., & Dillon, H. (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,* 128-146.

Cameron, S., & Dillon, H. (2007a). Development of the Listening in Spatialized Noise-Sentences Test (LISN-S). *Ear and Hearing, 28*(2), 196-211.

Cameron, S., & Dillon, H. (2007b). Listening in Spatialized Noise-Sentences test (LiSN-S) [computer software]. Sydney: National Acoustic Laboratories.

Cameron, S., & Dillon, H. (2007c). The listening in spatialized noise-sentences test (LISN-S): test-retest reliability study. *International Journal of Audiology, 46,* 145-153.

Cameron, S., Dillon, H., & Newall, P. (2006). Development and Evaluation of the Listening in Spatialized Noise Test. *Ear and Hearing*, *27*(1), 30-42.

Chermak, G.D., Hall III, J.W., & Musiek, F.E. (1999). Differential Diagnosis of Central Auditory Processing Disorder and Attention Deficit Hyperactivity Disorder. *Journal of the American Academy of Audiology, 10,* 289-303.

Chermak, G.D., & Lee, J. (2005). Comparison of Children's Performance on Four Tests of Temporal Resolution. *Journal of the American Academy of Audiology, 16,* 554-563.

Chermak, G.D., & Musiek, F.E. (1997). Central Auditory Processing Disorders: New Prospectives. San Diego, CA: Singular Publishing Group.

Colorado Department of Education (2008). (Central) Auditory Processing Deficits: A Team Approach to Screening, Assessment & Intervention Practices. Denver, CO. Task Force on Auditory Processing.

Croen, L.A., Grether, J.K., Hoogstrate, J., & Selvin, S. (2002). The Changing Prevalence of Autism in California. *Journal of Autism and Developmental Disorders, 32*(3), 207-215.

Dau, L. (2011). *Effects of maturation on a behavioral test battery of auditory processing* (Unpublished doctoral thesis). Towson University, Towson, Maryland.

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 and Hearing, 4*(6), 300-305.

Flax, J.F., Realpe-Bonilla, T., Brzustowicz, L.M., Bartlett, C.W., & Tallal, P. (2003). Specific Language Impairment in Families: Evidence for Co-Occurrence with

Reading Impairments. *Journal of Speech, Language, and Hearing Research, 46,* 530-543.

Flood, G. M., Dumas, H. M., & Haley, S. M. (2005). Central auditory processing and social functioning following brain injury in children. *Brain Injury, 19*(12), 1019-1026.

Gelfand, S.A., & Piper, N. (1981). Acoustic reflex thresholds in young and elderly subjects with normal hearing. *Journal of Acoustical Society of America*, *69*(1), 295-297.

Gelfand, S.A,. & Piper, N. (1983). Acoustic Reflex Threshold: Variability and Distribution Effects. *Ear and Hearing*, *5*, 228-234.

Ghazanfar, A.A., & Schroeder, C.E. (2006). Is neocortex essentially multisensory? *TRENDS in Cognitive Sciences, 10*(6), 278-285.

Heiervang, E., Stevenson, J., & Hugdahl, K. (2002). Auditory processing in children with dyslexia. *Journal of Child Psychology and Psychiatry, 43*(7), 931-938.

Iliadou, V., Bamiou, D.E., Kaprinis, S., Kandylis, D., & Kaprinis, G. (2009). Auditory Processing Disorders in children suspected of Learning Disabilities-A need for screening? *International Journal of Pediatric Otorhinolaryngology*, *73,* 1029-1034.

Jerger, J. (1970). Clinical Experience with Impedance Audiometry. *Archives of Otolaryngology*, *92*(4), 311-324.

Jerger, J., Chmiel, R., Allen, J., & Wilson, A. (1994). Effects of Age and Gender on Dichotic Sentence Identification. *Ear and Hearing*, *15*(4), 274-286.

Jerger, J., & Martin, J. (2006). Dichotic listening tests in the assessment of auditory processing disorders. *Audiological Medicine, 4*, 25-34.

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*(9), 467-74.

Katz, J. (1968). The SSW test: An interim report. *Journal of Speech and Hearing Disorders, 33*, 132-146.

Keith, R.W.(2000a). SCAN-C: Test for Auditory Processing Disorders in Children-Revised. San Antonio, TX: The Psychological Corporation.

Keith, R.W. (2000b). *Random Gap Detection Test*. St Louis: Auditec.

Keith, R.W. (2009). SCAN-3:C Tests for Auditory Processing Disorders for Children, San Antonio, TX: Pearson.

Kelly, A. (2007). Normative Data for Behavioural Tests of Auditory Processing for New Zealand School Children Aged 7 to 12 Years. *The Australian and New Zealand Journal of Audiology, 29*(1), 60-64.

Kimura, D. (1961). Cerebral dominance and the perception of verbal stimuli. *Canadian Journal of Psychology, 15*(3), 166-171.

Marshall, C.M., Snowling, M.J., & Bailey, P.J. (2001). Rapid Auditory Processing and Phonological Ability in Normal Readers and Readers with Dyslexia. *Journal of Speech, Language, and Hearing Research, 44*, 925-940.

McArthur, G.M., & Bishop, D.V.M. (2001). Auditory Perceptual Processing in People with Reading and Oral Language Impairments: Current Issues and Recommendations. *Dyslexia, 7*, 150-170.

McArthur, G.M., & Bishop, D.V.M. (2004). Frequency Discrimination Deficits in People With Specific Language Impairment: Reliability, Validity, and Linguistic Correlates. *Journal of Speech, Language, and Hearing Research, 47*, 527-541.

Meyers, J.E., Roberts, R.J., Bayless, J.D., Volkert, K., & Evitts, P.E. (2002). Dichotic listening: Expanded norms and clinical application. *Archives of Clinical Neuropsychology, 17*, 79-90.

Moncrieff, D.W. (2011). Dichotic listening in children: Age-related changes in direction and magnitude of ear advantage. *Brain and Cognition*, *76*(2), 316-322.

Moncrieff, D.W., & Musiek, F.E. (2002). Interaural Asymmetries Revealed by Dichotic Listening Tests in Normal and Dyslexic Children. *Journal of the American Academy of Audiology*, *13*, 428-437.

Moncrieff, D.W., & Wilson, R.H. (2009). Recognition of Randomly Presented One-, Two-, and Three-Pair Dichotic Digits by Children and Young Adults. *Journal of the American Academy of Audiology, 20*, 58-70.

Moore, D. R. (2006). Auditory processing disorder (APD): Definition, diagnosis, neural basis, and intervention. *Audiological Medicine*, *4*(1), 4-11.

Moore, D.R., Ferguson, M.A., Edmondson-Jones, A.M., Ratib, S., & Riley, A. (2010). Nature of Auditory Processing Disorder in Children. *Pediatrics, 126*(2), 382-390.

Moore, D.R., Hartley, D., & Hogan, S. (2003). Effects of otitis media with effusion (OME) on central auditory function. *International Journal of Pediatric Otorhinolaryngology, 67*(1), S63-S67.

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

Musiek, F.E. (1983b). Assessment of Central Auditory Dysfunction: the Dichotic Digit Test Revisited. *Ear and Hearing, 4,* 79-81.

Musiek, F.E. (1994). Frequency (pitch) and Duration Pattern Tests. *Journal of the American Academy of Audiology, 5*, 265-268.

Musiek, F.E., Baran, J.A., & Pinheiro, M. (1990). Duration pattern recognition in normal subjects and in patients with cerebral and cochlear lesions. *Audiology, 29*(6), 304-313.

Musiek, F.E., Bellis, T.J., & Chermak, G.D. (2005). Nonmodularity of the Central Auditory Nervous System: Implications for (Central) Auditory Processing Disorder. *American Journal of Audiology, 14,* 128-138.

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 Otology, 12*(2), 109-113.

Musiek, F.E., Shinn, J.B., Jirsa, R., Bamiou, D.E., Baran, J.A., & Zaidan, E. (2005). GIN (Gaps-in-Noise) Test Performance in Subjects with Confirmed Central Auditory Nervous System Involvement. *Ear and Hearing, 26*(6), 608-618.

Neijenhuis, K., Snik, A., Priester, G., van Kordenoordt, S., & van der Broek, P. (2002). Age effects and normative data on a Dutch test battery for auditory processing disorders. *International Journal of Audiology, 41,* 334-346.

Ono, K., Nakamure, A., Yoshiyama, K., Kinkori, T., Bundo, M., Kato, T., & Ito, K. (2011). The effect of musical experience on hemispheric lateralization in musical feature processing. *Neuroscience Letters, 496,* 141-145.

Palfery, T.D., & Duff, D. (2007). Central Auditory Processing Disorders: Review and Case Study. *Axon, 28* (3). 20-23.

Sandford, J. A., & Turner, A. (1995). *Manual for the Integrated Visual and Auditory Continuous Performance Test.* Richmond, VA, Braintrain.

Semel, E.M., Wiig, E.H., & Secord, W. (2003) *Clinical Evaluation of Language Fundamentals-Fourth Edition, Examiner's Manual.* San Antonio, TX: The Psychological Corporation.

Sharma, M., Purdy, S.C., & Kelly, A.S. (2009). Comorbidity of Auditory Processing, Language, and Reading Disorders. *Journal of Speech, Language, and Hearing Research, 52,* 706-722.

Silman, S., Silverman, C.A., & Emmer, M.B. (2000). Central Auditory Disorders and Reduced Motivation: Three Case Studies. *Journal of the American Academy of Audiology, 11,* 57-63.

Szatmari, P., Boyle, M., & Offord, D.R. (1989). ADHD and conduct disorder: degree of diagnostic overlap and differences among correlates. *Journal of the American Academy of Child and Adolescent Psychiatry, 28,* 865-872.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1999). *Comprehensive Test of Phonological Processing, Examiner's Manual*. Austin, TX: PRO-ED.

Wilson, R.H., Preece, J.P., Salamon, D.L., Sperry, J.L., & Bornstein, S.P. (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,* 269-277.

Witton, C. (2010). Childhood auditory processing disorder as a developmental disorder: The case for a multi-professional approach to diagnosis and management. *International Journal of Audiology, 49,* 83-87.

Yeargin-Allsopp, M., Rice, C., Karapurkar, T., Doernberg, N., Boyle, C., & Murphy, C. (2003). Prevalence of Autism in a US Metropolitan Area. *Journal of the American Medical Association*, *289*(1), 49-55.

CURRICULUM VITA

Julie Boiano

2503 Fleet Street, Baltimore, MD 21224

Audiology

Doctor of Audiology (Au.D.), May 2013

Education:

TOWSON UNIVERSITY – Towson, MD
Doctor of Audiology (Au.D.), August 2009 - Present
Anticipated graduation: May 2013

JAMES MADISON UNIVERISTY – Harrisonburg, VA
Bachelor of Science in Communication Sciences and Disorders, May 2009

Clinical Experience:

THE LISTENING CENTER AT JOHNS HOPKINS – Baltimore, MD
Audiology Student Clinician, January 2012 – May 2012

ENTAA CARE – Glen Burnie & Columbia, MD
Audiology Student Clinician, September 2011 – December 2011

KENNEDY KRIEGER INSTITUTE – Baltimore, MD
Johns Hopkins Pre-Doctoral Trainee, January 2011 – August 2011

TOWSON UNIVERSITY SPEECH, LANGUAGE & HEARING CENTER – Towson, MD
Audiology Student Clinician, January 2010 – December 2010