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EFFECTS OF MATURATION ON A BEHAVIORAL TEST BATTERY OF AUDITORY PROCESSING

by

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THESIS APPROVAL PAGE

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ABSTRACT

Effects of Maturation on a Behavioral Test Battery of Auditory Processing

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Data was collected on typically developing, normal hearing children between the ages of 7 and 12 years (n = 28) using a concise yet comprehensive battery of behavioral tests of auditory processing including the FPT, DPT, RGDT, DDT, CRW, and MLD. The extraneous variables of language ability, attention, phonological processing, and intelligence were taken into consideration through the administration of screening measures in these areas. Maturational effects were analyzed using MANOVA to identify differences in performance between the three age groups of children (7-8 year olds; 9-10 year old; 11-12 year olds). A comparison between right and left ear scores did not reveal significant differences between ear scores on any of the monaurally scored AP tests. Because of this, average scores were also used in the data analysis. Statistically significant differences were found on the FPT, DPT, and DDT tests between the age groups with better performance observed for older children compared to younger children. Auditory processing performance was not significantly different between male and female participants. Additionally, a regression analysis revealed that auditory processing test performance was not a significant predictor of non-verbal IQ score. In order to comprehensively evaluate auditory processing abilities in children, audiologists should select tests that assess a wide array of underlying auditory skills such as sound localization and lateralization, auditory discrimination, dichotic listening, auditory pattern

recognition, temporal processing, and performance with competing or degraded acoustic signals (AAA, 2010; ASHA, 1996; 2005a). With the exception of the 500 Hz MLD test, the comprehensive auditory processing test battery used in this study has clinical utility for children 7 to 12 years of age. A lack of statistically significant maturational effects on some of the tests in the battery may be attributed to the small sample size used in this study. The collection of additional participant data using the same methodology as the current study will assist in creating local normative data and a comprehensive auditory processing test battery for the Maryland area.

Abbreviations: AAA = American Academy of Audiology; ABR = Auditory Brainstem Response; ADHD = Attention Deficit Hyperactivity Disorder; AFT-R = Auditory Fusion Test- Revised; APD = Auditory Processing Disorder; ART = Acoustic Reflex Threshold; ASHA = American Speech Language Hearing Association; BF = Binaural Fusion; CAEP = Cortical Auditory Evoked Potential; CANS = Central Auditory Nervous System; (C)APD = (Central) Auditory Processing Disorder; CELF-4 = Clinical Evaluation of Language Fundamentals, Fourth Edition; CID = Central Institute for the Deaf; CNS = Central Nervous System; CRW = Compressed and Reverberated Words; CTOPP = Comprehensive Test of Phonological Processing; CVC = Consonant-vowel-consonant; DDT = Dichotic Digits Test; DL = Difference Limen; DPT = Duration Pattern Test; FPT = Frequency Pattern Test; GIN = Gaps in Noise; IRB = Institutional Review Board; ISI = Interstimulus Interval; IVA-CPT = Integrated Visual and Auditory Continuous

Performance Test; LISN = Listening in Spatialized Noise; M = Mean; MANOVA = Multivariate Analysis of Variance; MLD = Masking Level Difference; MLR = Middle Latency Response; MMN = Mismatch Negativity; NU-6 = Northwestern University Auditory Test No. 6; OME = Otitis media with effusion; PB-K = Phonetically Balanced-Kindergarten; PE = Pressure equalization; PPS = Pitch Pattern Sequence; RASP = Rapidly Alternating Speech Perception; RDDT = Random Dichotic Digits Test; REA = Right ear advantage; RGDT = Random Gap Detection Test; SCAN = Screening Test for Auditory Processing Disorders; SD = Standard deviation; SNR = Signal to Noise Ratio; TEOAE = Transient Evoked Otoacoustic Emissions; TONI-3 = Test of Nonverbal Intelligence, Third Edition; VA = Veterans Administration; WRS = Word Recognition Score

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CHAPTER 1

Introduction

Auditory processing disorder (APD) refers to the abnormal processing of auditory information within the central auditory nervous system (CANS) despite normal peripheral hearing sensitivity (Jerger & Musiek, 2000). Individuals with APD are behaviorally characterized as having difficulties understanding rapid or degraded speech, localizing sound sources, following multiple step oral directions, and/or sustaining attention to auditory messages (Bamiou, Musiek, & Luxon, 2001). This population will experience behavioral performance deficits in one or more auditory skills including sound localization and lateralization, auditory discrimination, dichotic listening, auditory pattern recognition, temporal processing, and performance with competing or degraded acoustic signals (AAA, 2010; ASHA, 1996; 2005a). In order for audiologists to accurately diagnose APD, behavioral tests should be administered that assess each of these underlying auditory skills. In order to determine whether a child's performance on a specific test in the battery is abnormal, the results are compared to age appropriate normative data. Normative data are needed for various age groups of children up to 10 to 12 years of age, when myelination of the CANS is complete (Musiek, Gollegly, & Baran, 1984). If local normative data are not available, audiologists are encouraged to obtain their own normative data (AAA, 2010; Emanuel, 2002; Windham, Parks, & Mitchener-Colston, 1986).

The aim of this study was to collect data on typically developing children between the ages of 7 and 12 years using a concise yet comprehensive battery of behavioral tests of auditory processing that requires minimal linguistic loading. The extraneous variables

of language ability, attention, phonological processing, and intelligence were taken into consideration through the administration of screening measures in these areas. Maturational effects were analyzed with respect to performance of different age groups of children. The results of this normative study will be used to assist audiologists in APD diagnosis.

CHAPTER 2

Literature Review

The human auditory system is a complex pathway that extends from the outer ear to the auditory cortex. A normally functioning outer, middle, and inner ear are the major peripheral components responsible for sending auditory information to the CANS. The auditory input ultimately arrives at the auditory cortex where conscious sound processing occurs and the auditory information becomes meaningful. Even when peripheral hearing sensitivity is within normal limits, a person may have difficulty processing auditory input within the CANS. Behaviorally, this person may present with difficulties understanding rapid or degraded speech, localizing sound sources, following multiple step oral directions, and/or sustaining attention to auditory messages (Bamiou et al., 2001). Language, reading, spelling, and attention disorders are also common in this population (Bamiou et al., 2001; Sharma, Purdy, & Kelly, 2009). Auditory processing can be defined as “the efficiency and effectiveness by which the central nervous system (CNS) utilizes auditory information” (ASHA, 2005a, p. 2). Auditory Processing Disorder (APD), also known as (Central) Auditory Processing Disorder ([C]APD), refers to the abnormal processing of auditory information within the CNS despite normal peripheral hearing thresholds (Jerger & Musiek, 2000). The American Speech-Language-Hearing Association (ASHA) Technical Report (2005a) further defines this condition as a deficit in the “perceptual processing of auditory information in the CNS and the neurobiologic activity that underlies that processing and gives rise to the electophysiologic auditory potentials” (p. 2). Individuals with APD or (C)APD experience deficits in one or more auditory skills including sound localization and lateralization, auditory discrimination, dichotic listening, auditory pattern recognition, temporal processing, and performance with competing or degraded acoustic signals (AAA, 2010; ASHA, 1996; 2005a). A test battery approach is recommended that targets the assessment of these auditory processes; however, a “gold” standard for APD assessment has not been adopted clinically. Omission of the term “central” was recommended by some professionals in order to minimize the focus on anatomical location and to stress the complex relationship between peripheral and central contributions to the disorder (Chermak, 2002; Jerger & Musiek, 2000; Moore, 2006). Additionally, the use of both terms “central” and “processing” is redundant (English, 2007). Despite this recommendation, the terms APD and (C)APD are often used interchangeably in the relevant literature and should be interpreted synonymously (ASHA, 2005a). To be consistent with much of the current literature, the term APD will be used throughout this paper.

Differential Diagnosis of APD

Auditory processing disorder is the result of abnormal processing of auditory input within the CANS due to either a localized auditory impairment or a more generalized impairment affecting multiple modalities (ASHA, 1996; Silman, Silverman, & Emmer, 2000). Early research in the area of auditory processing was used to identify patterns of auditory performance in patients with documented lesions or pathology of the CANS (Hurley & Musiek, 1997; Musiek, Baran, & Pinherio, 1990; Musiek, Gollegly, Kibbe, & Verkest-Lenz, 1991; Musiek & Pinheiro, 1987). These studies established the sensitivity and specificity of behavioral tests of auditory processing related to dichotic listening and temporal patterning abilities (AAA, 2010). Auditory processing disorder has more recently gained clinical attention in school-aged children due to the link between auditory processing and learning (Cacace & McFarland, 1998; Dawes & Bishop, 2009; Sharma et al., 2009; Stollman, van Velzen, Simkens, Snik, & van den Broek, 2004; Tallal, Miller, & Fitch, 1993). This is because speech understanding requires several auditory skills including discrimination of subtle changes in frequency, timing, and intensity of sounds; attending to the signal of interest; and differentiating the intended signal from background noise (Bailey & Snowling, 2002). Some school-aged children may experience auditory processing deficits secondary to neurological disorders or pathologies such as tumors, cerebrovascular insults, metabolic disorders, epilepsy, or brain damage (Bamiou et al., 2001). Others will present with auditory processing difficulties associated with developmental abnormalities including attention deficit hyperactivity disorder (ADHD), dyslexia, language impairment, or learning disabilities (Bamiou et al., 2001). Sharma et al. (2009) assessed auditory processing, reading, and language abilities in children suspected of APD and found that reading disorder and language impairment more commonly co-occurred with APD than each disorder occurred in isolation. Other children may experience auditory processing difficulties due to delayed maturation of the CANS pathways (Bamiou et al., 2001). This group may include children who experienced periods of auditory deprivation due to chronic episodes of otitis media with effusion (OME; Bamiou et al., 2001). Even though these sub-groups of children may have involvement of different modalities, each will likely present with similar auditory behaviors consistent with APD due to a disruption in the processing of information with the CANS (Bellis & Ferre, 1999). Because effective processing of auditory information is essential to receptive language and overall learning, auditory difficulties are often a common complaint linking this heterogeneous population and resulting in a referral to an audiologist for comprehensive assessment (Bellis & Ferre, 1999).

Multidisciplinary team approach.

Due to the complexity of the CANS, it is not feasible to assess the auditory modality in isolation (Dawes & Bishop, 2009). The role of the audiologist in the differential diagnosis of APD is to evaluate the auditory behaviors and skills of children suspected of APD while minimizing the potential confounding effects of other processes such as language, attention, or cognition (ASHA, 2005b; Cameron, Dillon, & Newall, 2005; Jerger & Musiek, 2000). Riccio, Cohen, Garrison, and Smith (2005) found that selected tests of auditory processing correlated with each other; however, correlations with attention, memory, and behavior did not reach levels of statistical significance. Other researchers found conflicting evidence that auditory processing tests were sensitive to disorders of attention (Cook et al., 1993) and learning (Gomez & Condon, 1999). Silman et al. (2000) reported case studies of children who were initially diagnosed with APD based on poor behavioral test performance; however, upon retesting with a tangible reinforcer, scores improved to within normal range. The authors hypothesized that this change was due to motivational factors as opposed to true APD (Silman et al., 2000). To determine whether auditory complaints are a result of APD or due to other disorders, a multidisciplinary team of professionals is needed (AAA, 2010; ASHA, 1996, 2005a, 2005b; Cameron et al., 2005; Chermak, 2002; Riccio et al., 2005).

Although the official diagnosis of APD is made by audiologists, additional assessments, intervention, and management of the disorder requires a team approach of professionals including speech-language pathologists, educators, psychologists, and physicians (AAA, 2010; Chermak, 2002). These professionals are responsible for differential diagnosis, or ruling out potential co-morbid conditions that may impact auditory processing test results through the assessment of receptive and expressive language abilities, psychoeducational progress, health status, metalanguage, and/or metacognition (Chermak, 2002).

Minimum suggested test battery.

Audiologists are responsible for the clinical diagnosis of APD and therefore must select a test battery that is sensitive and specific to this disorder (AAA, 2010; ASHA, 2005a, 2005b; Chermak, 2002). Jerger and Musiek (2000) proposed a minimum test battery for audiologists to diagnose APD which includes behavioral, electroacoustic, and electrophysiologic tests. Since the goal of auditory processing assessment is to examine the integrity of the CANS, it is necessary to evaluate peripheral hearing sensitivity prior to the administration of auditory processing tests to rule out the presence of middle ear or cochlear dysfunction (AAA, 2010; ASHA, 2005a; Jerger & Musiek, 2000). At minimum, it is recommended that this test battery include Distortion Product Otoacoustic Emissions (DPOAEs) to evaluate the functioning of the outer cochlear hair cells, acoustic immittance measures including tympanometry and acoustic reflexes, pure tone air conduction audiometry at traditional octave frequencies as well as 3000 and 6000 Hz, and word recognition testing in quiet (AAA, 2010). Jerger and Musiek (2000) further recommend obtaining performance intensity functions for word recognition testing in order to compare word recognition abilities at different presentation levels and between the ears. In the presence of a mild to moderate peripheral hearing impairment and adequate speech recognition abilities, test selection and administration may be modified to assess auditory processing abilities; however, results must be interpreted cautiously (ASHA, 2005a; Chermak, 2002). Jerger and Musiek (2000) also recommend auditory brainstem response (ABR) and middle latency response (MLR) testing as part of the minimal test battery in order to gather information about the auditory structures at the level of the brainstem. The most recent APD professional guidelines suggest situations in which the inclusion of auditory evoked potentials would be beneficial to APD assessment as part of an extended test battery (AAA, 2010); however, these measures have limited use in a minimal test battery. Behavioral auditory processing tests should be administered that assess at least the underlying auditory processes of dichotic listening, auditory pattern recognition, and temporal processing (Jerger & Musiek, 2000). Because of the potential for auditory deficits in one or more of the underlying auditory processes, a test battery approach is needed (AAA, 2010).

Surveys of common practices in APD assessment.

Recent surveys of common audiologic practices in auditory processing assessment have revealed non-compliance with these recommended guidelines (Chermak, Silva, Nye, Hasbrouck, & Musiek, 2007; Chermak, Traynham, Seikel, & Musiek, 1998; Emanuel, 2002). Of the 179 total respondents to a survey conducted in 1998, 41% (n = 74) reported administering tests to assess auditory processing or CANS function (Chermak et al., 1998). The majority (69%) of these audiologists reported using a test battery approach, but approximately half of these respondents expressed minimal satisfaction with the test battery used. In general, the most commonly used diagnostic tests reported were acoustic reflex testing, ABR, and the Screening Test for Auditory Processing Disorders (SCAN). The original SCAN included subtests of filtered words, auditory figure ground, and competing words (Domitz & Schow, 2000). This test has since been revised for use as a screening and/or diagnostic tool, the SCAN-3, which includes separate versions for children and adolescents/adults (Keith, 2009a, 2009b). Overall, the results of this national survey highlighted the need for improvement in academic and clinical preparation of audiologists in the assessment of APD (Chermak et al., 1998).

Emanuel (2002) found that only 15% (n = 28) of audiologists reported administering tests to assess auditory processing or CANS function; however, none of these audiologists fully complied with the recommended guidelines for APD assessment of pediatric patients as specified by Jerger and Musiek (2000). Results of this survey found overall compliance with the recommended protocol for basic audiologic assessment with the exception of performance intensity functions for word recognition testing and electrophysiology tests. The most commonly used auditory processing tests were dichotic speech tests and monaural low redundancy speech tests in addition to questionnaires. Use of a frequency pattern test to assess temporal processing was reported by the majority of respondents; however, duration pattern and gap detection tests were not commonly reported. Auditory brainstem response testing was reported as part of an extended test battery; however, most electrophysiologic tests, especially later potentials, were omitted from both the standard and extended test batteries (Emanuel, 2002).

A more recent national online survey conducted by Chermak et al. (2007) found that only 27% (n = 24) of audiologists surveyed assessed the integrity of the CANS to diagnose APD. Some of the identified contraindications to testing were English as a second language, low IQ, cognitive deficit, or language delay. Additionally, the majority

(76%) of these audiologists reported omission of a team approach in APD diagnosis and management. The most commonly used diagnostic measures were acoustic reflex threshold (ART) testing, speech recognition testing in noise, competing sentences, and pitch pattern testing. Although Chermak and colleagues (2007) suggested there was an overall improvement in APD assessment practices since 1998, they stated that further development and education was needed to effectively assess children for APD. The results of this study should be interpreted with caution due to the limited number of respondents who completed the entire survey.

Consideration of patient factors and task variables.

Prior to the administration of diagnostic tests, several patient factors and task variables need to be taken into consideration. Patient factors may include chronological and cognitive age, behavior, speech-language development, motor development, peripheral hearing sensitivity, educational history, medical history, co-morbid diagnoses, medications, social development, linguistic and cultural background, prior or current therapies, visual acuity, motivation, fatigue, and attention (AAA, 2010; Jerger & Musiek, 2000). Much of this information can be gathered through a comprehensive case history obtained from the child’s caregiver and thorough review of relevant professional reports (AAA, 2010). This may be supplemented by an interview with the primary caregiver, informal observation of the child, or completion of formal observation inventories or checklists by the caregiver or educator (AAA, 2010). Behaviors that are commonly reported for children with APD include difficulty understanding speech in the presence of background noise or reverberation, difficulty localizing sound sources, frequent requests for repetition, inappropriate responses to requests, poor musical appreciation or ability, difficulty following rapid speech, and academic difficulties (AAA, 2010). These behavioral symptoms are not unique to APD, but may be useful to determine candidacy for APD assessment (AAA, 2010).

Attention deficit hyperactivity disorder is one childhood condition that may share similar behavioral characteristics with APD and has led to controversy as to whether APD and ADHD are distinct clinical entities (Chermak, Hall, & Musiek, 1999). Chermak, Tucker, and Seikel (2002) surveyed audiologists and pediatricians to determine the most common behavioral symptoms associated with APD and ADHD (predominantly inattentive type). The most commonly reported symptoms of ADHD by pediatricians were inattentiveness and academic difficulties, whereas the most commonly reported symptoms of APD reported by audiologists were frequent requests for repetition and poor listening abilities. Only two of the most common 11 behavioral symptoms reported by these professionals were the same between the two groups. Overall, the results of this study suggest that the professionals responsible for diagnosing these disorders associate a different set of symptom criteria (Chermak et al., 2002).

Consideration of the comprehensive listener variables described above will guide appropriate test selection for a child suspected of APD and provide insight to potential co-morbid conditions in need of referral to other professionals on the multidisciplinary team (AAA, 2010). The information gathered may also reveal functional deficits that will be used to guide future intervention and management efforts (AAA, 2010).

Task variables are another important consideration in the selection of behavioral tests of auditory processing (Jerger & Musiek, 2000). Potential task variables include cognitive requirements such as memory, floor and ceiling effects, learning effects, practice effects, language requirements, and the desired response mode. For example, Neijenhuis, Snik, Priester, van Kordenoordt, and van den Broek (2002) encountered ceiling effects on seven out of eight behavioral auditory processing tests when using a Dutch test battery to explore maturational effects from childhood to adolescence. The ceiling effects were evidenced by an abnormal distribution of scores. Due to ceiling effects, the results of the study could not be interpreted using the traditional method of auditory processing test interpretation by calculating means (M) and standard deviations (SD). Percentile scores were used instead (Neijenhuis et al., 2002). Another example of task variables that can affect test interpretation relates to the language requirements of the desired response mode. The task of verbally labeling a pattern of tones versus humming the pattern may confound test interpretation for some children due to the added task of supplying a linguistic label for the tone. The task of humming the tone pattern requires the right hemisphere, while verbally labeling the tone pattern requires both hemispheres and the corpus callosum (Mukari, Umat, & Othman, 2010). Contrary to the standard verbal response mode suggested for adults by Musiek (1994) for duration and frequency pattern tests, Stollman et al. (2004) did not require children to produce a verbal response for tests of temporal patterning. These researchers found that temporal patterning tests could be used for young children using this response method.

Maturation of Auditory Processing

Evidence from electrophysiologic studies.

When assessing the auditory processing abilities of children, the effects of maturation must be considered in order to differentiate between a disordered and an immature auditory system (ASHA, 1996; Neijenhuis, Snik, & van den Broek, 2003). At the time of birth, the peripheral auditory system is essentially mature; however, the central auditory system continues to develop into childhood (Moore & Linthicum, 2007; Schochat & Musiek, 2006; Werner, 2007). The CANS is comprised of a complex network of neural pathways extending from the cochlear nucleus in the brainstem to the auditory cortex (Bamiou et al., 2001). As children grow and develop, these pathways constantly change. These changes are evident in electrophysiologic testing.

During the third trimester to the sixth postnatal month of development, myelination of the brainstem pathways and increased cellular density cause ABR latencies to become comparable to adults, suggesting a mature brainstem pathway (Moore & Linthicum, 2007). During this time, axons from the inferior colliculus project to the medial geniculate body. Myelination of these axonal projections is believed to contribute to the detection of the MLR, specifically the Po-Na complex (Moore & Linthicum, 2007). By approximately 3 months of age, the latency of the Na peak of the MLR reaches adult-like latencies (Moore & Linthicum, 2007). The Na peak is associated with maturation of the upper levels of the brainstem (Moore & Linthicum, 2007). Cortical development, however, takes longer to mature (Moore & Guan, 2001). Between 6 and 12 months of age, babies become more responsive and attentive to features of their native language as evidenced by both behavioral responses and objective testing (mismatch negativity (MMN) responses; Moore & Linthicum, 2007). Between 2 and 5 years of age, auditory evoked cortical potentials are measureable, specifically the Pa and P_1 potentials, but are not adult-like until later childhood. These peaks are believed to be generated from deep cortical layers. As children get older (6 to 12 years), superficial layers of the auditory cortex develop as suggested by the emergence of a negative deflection following the positive P_1 peak, known as N_1. This potential can be reliably recorded in children by approximately 9 years of age, but can be recorded in younger children (ages 6 to 8 years) using slower stimulation rates (Moore & Linthicum, 2007). Myelination of the corpus callosum in typically developing children is believed to continue until at least 10 years of age, decreasing the processing time between the brain hemispheres (Musiek et al., 1984). The maturational changes of the auditory cortex displayed by cortical auditory evoked potentials (CAEPs) are believed to be linked to the advancing auditory processing abilities seen as children age such as improvements in speech perception in the presence of noise (Moore & Linthicum, 2007; Ponton, Eggermont, Kwong, & Don, 2000).

Stages of auditory development.

Before complex auditory processing skills emerge, children must achieve basic stages of auditory development. Werner (2007) describes three broad stages of postnatal auditory development ranging from birth to school-age. From birth to 6 months of age, infants are unable to discriminate subtle differences in the frequency or intensity of auditory stimuli and are less sensitive to sound than adults as evidenced by significantly elevated behavioral thresholds, especially at higher frequencies. Although this is due in part to the efficiency of the middle ear system, loss of energy at the level of the brainstem due to slower processing speed is also believed to play a role (Werner, 2007). Frequency resolution matures by 6 months of age; however, behavioral threshold sensitivity continues to be poorer than that of adults. By school-age, children’s behavioral hearing thresholds are generally adult-like and their ability to attend to and discriminate sounds, even in challenging listening environments, has improved significantly. Consistent exposure to sound is needed during childhood in order to progress through these auditory stages so that important neural connections can be made and sound can be encoded appropriately in the brain (Werner, 2007).

Age Effects in Behavioral Tests of Auditory Processing

Categories of behavioral auditory processing tests.

In order to comprehensively evaluate a child's auditory processing abilities, there are specific behavioral tests designed to assess different underlying auditory processes. These tests are administered clinically by audiologists. These categories of tests may include auditory discrimination, temporal processing, dichotic listening, monaural low redundancy, binaural interaction, and sound localization and lateralization (AAA, 2010; ASHA, 2005a). Auditory discrimination tasks require the listener to detect subtle changes in the basic acoustic parameters of sound including frequency, duration, or intensity. Temporal processing involves the processing of acoustic events occurring over time. Tests in this category may assess the processes of temporal resolution, temporal discrimination, temporal masking, temporal integration, temporal ordering or sequencing, localization, or pitch perception. Dichotic listening involves the presentation of different auditory stimuli to each ear. The task of the patient is to repeat both stimuli or to repeat only the stimuli heard in a specific ear. These dichotic listening tasks are designed to assess the underlying auditory processes of binaural integration and binaural separation, respectively. Monaural low redundancy speech tests assess the ability of the auditory system to achieve auditory closure when the acoustic signal is distorted or less clear due to the effects of filtering, reverberation, competing noise or speech, or time compression. Tests of binaural interaction are similar to dichotic listening tasks; however, the stimuli may be presented in a sequential rather than a simultaneous manner, and may require the listener to integrate the disparate stimuli into a unified message (Bellis, 2003). Tests of localization and lateralization involve determining the extrinsic and intrinsic location of a sound, respectively. The Listening in Spatialized Noise (LISN) test is designed to assess the processes of localization and lateralization, and is currently in the stages of normative data collection (AAA, 2010). In general, the categories of behavioral tests described above can be administered to children beginning at 7 years of age.

Due to the challenging nature of behavioral tests of auditory processing, high variability of scores when re-tested, and lack of normative data, these tests are not recommended for children younger than 7 years of age (AAA, 2010; Bellis, 2003; Chermak, 2002). Instead, screening tools, behavioral checklists, or behavioral tests that have normative data available (i.e. Pitch Pattern Sequence or Pediatric Speech Intelligibility Test) for younger populations may be more appropriate in order to determine whether these younger children are “at risk” for APD (AAA, 2010). In order to determine whether the results of behavioral tests of auditory processing are delayed or disordered, extensive age-appropriate normative data must be collected until approximately 12 years of age, when auditory processing abilities of children reach adult levels (Bellis, 2003; Stollman et al., 2004). Normative data for behavioral auditory processing tests for age groups up to 12 years need to be collected in order to determine normal versus abnormal cut-off scores that will be used to accurately diagnose APD in children.

Auditory discrimination.

When the auditory discrimination abilities of children between the ages of 4 and 6 years were compared to adults, Jensen and Neff (1993) found that intensity discrimination matured first, followed by frequency discrimination, and then duration discrimination. These researchers measured discrimination skills using the smallest discriminable difference, or difference limen (DL), which was calculated by a computer. The children were presented binaurally with three stimuli and were asked to identify which of the stimuli sounded different from the standard stimulus. A 440 Hz, 400 ms pure tone presented at 70 dB SPL was used as the standard stimulus and was varied in increments of 1 to 25 dB for intensity discrimination tasks, 1 to 400 Hz for frequency discrimination tasks, and 5 to 800 ms for duration discrimination tasks. Task difficulty increased as response accuracy increased. The DL was calculated based on the resulting psychometric function as the 70.7% correct point. Results showed that the intensity discrimination of children was comparable to adults by 5 years of age for the majority of the children in the study and for some of the 4 year olds. Due to the young age of the children in this study, tactics were used to promote successful completion of the tasks including tangible reinforcement, consistent positive feedback, practice items, and a stimulating computer-game test format with visual reinforcement. Frequency and duration discrimination was highly correlated with age, with poorer performance observed for the youngest children. The authors also noted considerable variability of scores for all participants on the frequency and duration discrimination tasks, and for the younger children on the duration discrimination task. The sequential development of auditory discrimination skills was linked to anatomical and physiological development since intensity and frequency discrimination abilities have been linked to lower levels of the auditory system compared to temporal (duration) discrimination which involves central cortical pathways (Jensen & Neff, 1993). Specific tests of auditory discrimination are not typically included by audiologists in auditory processing test batteries due to a lack of clinically available tests with normative data (AAA, 2010). Some auditory discrimination measures such as the Minimal Pairs Test (Robbins, Renshaw, Miyamoto, Osberger & Pope, 1988) and Wepman's Auditory Discrimination Test (Wepman & Reynolds, 1986) are more commonly included as part of speech-language assessments (AAA, 2010).

Temporal processing.

Tests of temporal patterning, including frequency (pitch) and duration pattern tests, are commonly used to assess temporal processing abilities. In the most widely used paradigm for these tests, three tones are presented monaurally and the listener must identify the pattern by assigning a verbal label to each tone or by humming the pattern. The frequency pattern test (FPT) presents a series of high (1122 Hz) or low (880 Hz) pitched tones of 150 ms duration (Musiek, 1994). The duration pattern test (DPT) presents a series of 1000 Hz tones of either short (250 ms) or long (500 ms) duration. Musiek et al. (1990) reported that 18 out of 21 patients with confirmed cerebral lesions performed below normal limits on the DPT. Musiek and Pinheiro (1987) reported 83% sensitivity and 88.2% specificity of the FPT to cerebral lesions. Despite a unilateral cerebral pathology, results of patterning tests revealed bilateral deficits most likely due to the response mode of verbal labeling (Musiek et al., 1990). Although lesion studies have found good sensitivity and specificity of both the FPT and DPT, each test is sensitive to different types of lesions. As a result, it is hypothesized that the FPT and DPT assess different underlying auditory processes (Musiek, 1994). Another temporal patterning test, the Pitch Pattern Sequence (PPS) test has been suggested for use in younger children. The PPS test has a child version with longer duration stimuli and longer interstimulus intervals (ISI; Pinheiro & Ptacek, 1971).

Normative data for New Zealand children collected by Kelly (2007) found that scores on the FPT improved with age from 7 to 12 years. A right ear advantage (REA) was noted for the 7, 0 to 8, 11 (years, months) age group only. Schochat and Musiek (2006) administered both pitch pattern and duration pattern tests to a sample of 55 Brazilian children divided into five age groups from 7 to 16 years. Significant age effects were found up to 12 years of age for both tests. No significant differences were found between the right and left ear scores. It was noted that the scores of both pattern tests were poorer than normative data published in the United States, possibly attributed to a lack of formal music education in the Brazilian school system or to characteristics of the Portuguese language such as greater redundancy and phoneme discrimination than English (Schochat & Musiek, 2006). Stollman et al. (2004) also found significant age effects on both the FPT and DPT in a longitudinal study of children between the ages of 6 and 12 years. Even though the scores of the youngest age group were variable, there was significant improvement in scores between the five different test occasions within this 6 year time span. Additionally, the age effect was greater for the DPT than the FPT. These authors suggested the use of temporal patterning tests when assessing the auditory processing abilities of children as young as 6 years of age. In a Dutch normative sample, no significant age effects were found for the FPT when comparing children, adolescents, and adults (Neijenhuis et al., 2002). The researchers attributed this to the lack of a normal distribution of scores due to ceiling effects.

Tests of temporal resolution, assessed either through gap detection or fusion, are also used to assess temporal processing abilities. A differentiation is made between gap detection and fusion, with the former referring to detection of a period of silence and the latter referring to a detection of two versus one sound (Shinn, Chermak, & Musiek, 2009). Commercially available tests of temporal resolution include the Random Gap Detection Test (RGDT; Keith, 2000b), Gaps in Noise test (GIN; Musiek, Shinn, Jirsa, Bamiou, Baran, & Zaidan, 2005), and Auditory Fusion Test-Revised (AFT-R; McCroskey & Keith, 1996). The RGDT uses tones at octave frequencies between 500 and 4000 Hz and click stimuli with random ISI ranging from 0 to 40 ms (Chermak & Lee, 2005). The use of tonal stimuli allows the clinician to obtain frequency specific information while the use of click stimuli is recommended as a screening measure (Chermak & Lee, 2005). An average composite gap detection threshold is calculated using the smallest discernable ISI obtained for each subtest (Chermak & Lee, 2005). With the RGDT, Kelly (2007) found that using a cut-off score of 2 SD below the mean, thresholds for three age groups of children from 7 to 12 years were within the published normative cut-off of 20 ms (Keith, 2000b). Additionally, the youngest age group (7 to 8 years old) had the highest (poorest) mean gap detection thresholds (Kelly, 2007). These results support the use of the same 20 ms upper limit of normal for both children and adult listeners.

The GIN is also a measure of gap detection using 6 s segments of white noise stimuli that are interrupted with random ISI ranging from 2 to 20 ms (Chermak & Lee, 2005). This test is presented monaurally at a comfortable listening level. The listener is instructed to respond by pressing a button whenever a silent gap is detected within the noise (Chermak & Lee, 2005). The gap detection threshold is the smallest ISI that is detected in at least 4 out of 6 presentations (Chermak & Lee, 2005). When temporal resolution was assessed using the GIN, no statistically significant age effects or ear effects were found between six age groups of typically developing children ranging from 7 to 18 years (Shinn et al., 2009). The results of this study suggest that maturation of temporal resolution occurs before 7 years of age and progresses symmetrically within the CANS.

Dichotic listening.

Dichotic listening tasks involve the simultaneous presentation of related speech stimuli (syllables, digits, spondees, or sentences) to both ears (Hällgren, Johnansson, Larsby, & Arlinger, 1998; Noffsinger, Martinez, & Wilson, 1994). The listener's task is to repeat the stimuli heard in both ears to assess binaural integration, or to repeat the stimuli heard in one ear only to assess binaural separation (Bellis, 2003). Kelly (2007) found dichotic listening abilities improved with age in a normative population of children from 7 to 12 years when assessed using the double digits version of the Dichotic Digits Test (DDT). A REA was noted for the 7, 0 to 8, 11 age group only; however, published normative data for the DDT reveals a REA for all age groups of children (Bellis, 2003). The reason for the expected REA on dichotic speech tests is related to the more efficient processing of information in the language dominant hemisphere (usually the left hemisphere) of the brain when accessed through the contralateral pathway (stimulation to the right ear; Hällgren et al., 1998; Moncrieff & Wilson, 2009). This hypothesis is supported by the results of testing dichotic listening abilities in split-brain patients (Musiek et al., 1989). It has been observed that older, school-aged children may reach ceiling levels on DDT using a closed set of double digits presented to each ear (Moncrieff & Musiek, 2002; Neijenhuis et al., 2002). Using the triple digit version of the DDT, significant age effects were found in a normative sample of Dutch participants (Neijenhuis et al., 2002). Specifically, significant age effects were noted between the children (9, 0 to 12, 0) and adolescents (14, 0 to 16, 0), but not between the adolescents and adults (18, 0 to 47, 0). A REA was found for all age groups in this study (Neijenhuis et al., 2002). Hällgren et al. (1998) assessed dichotic listening abilities in 30 normal hearing participants with no known central pathology using a variety of recorded Swedish speech stimuli including consonant-vowel syllables, digits, spondees, and sentences. The 30 participants were divided into three age groups: 11 year olds, 23-27 year olds, and 67-70 year olds. When a comparison was made between the different age groups of participants, no significant age effects were found for any of the dichotic speech tests, suggesting that dichotic listening abilities reach adult performance levels by 11 years of age (Hällgren et al., 1998).

Another potential dichotic listening task involves the random presentation of one, two, or three pairs of dichotic digits (Moncrieff & Wilson, 2009). The demanding nature of this task is related to the increased informational load on auditory memory when the number of stimuli increases, and the inability to predict the number of stimuli in each presentation. Moncrieff and Wilson (2009) assessed the underlying process of binaural integration using the random dichotic digits test (RDDT) in normal hearing participants between the ages of 10 and 28 years. Significant age effects were found, with scores increasing with age in both ears. Additionally, the magnitude of the difference scores between the ears was greatest in younger listeners and progressively decreased with age. Ceiling effects were noted for older listeners (Moncrieff & Wilson, 2009).

Monaural low redundancy.

Monaural low redundancy can be assessed using degraded speech stimuli through the addition of time compression, reverberation, filtering, or noise. This type of test assesses the listener's ability to achieve auditory closure when the speech signal is not as clear. Time compression affects the rate of the speech signal and is expected to have a greater negative impact on individuals with compromised central auditory systems compared to those with normal central auditory systems (Wilson, Preece, Salamon, Sperry, & Bornstein 1994). With the addition of reverberation, word recognition abilities are expected to decrease (Wilson et al., 1994). Using consonant-vowel-consonant (CVC) words recorded with a native New Zealand speaker and the addition of 65% time compression and 0.3 s reverberation, performance of a normative sample of children aged 7 to 12 years generally improved with age (Kelly, 2007). However, the author cautions that these results are limited due to the small sample size of 50 children further divided into three age groups. Phonemic scoring was used instead of whole word scoring to increase the number of test items without affecting test duration, consistent with clinical practice in New Zealand. A REA was expected on this test due to the linguistic demands; however, the results did not support this hypothesis (Kelly, 2007). Another normative data study assessed this skill in typically developing African American children living in urban communities (Windham et al., 1986). Using Phonetically Balanced Kindergarten (PB-K) words with time compression of 30% and 60% presented in the sound field, consistent performance was found across age groups from 7, 4 to 11, 3. Additionally, a significant difference was noted between the compression conditions, with better performance in the 30% condition than the 60% condition (Windham et al., 1986).

Filtering of speech is another way to assess the skill of auditory closure. When monosyllabic words were combination filtered (high pass at 3000 Hz and low pass at 500 Hz) and presented to a normative sample of Dutch children, adolescents, and adults, scores were not significantly different in the monaural or binaural conditions (Neijenhuis et al., 2002). Age effects were significant between the children and adults; however, comparison of adolescent data was not possible due to a technical recording error. Stollman et al. (2004) administered low-pass filtered CVC monosyllabic words to a group of children on five different occasions between the ages of 6 and 12 years. Maturational effects were found up to 12 years on this test when administered monaurally.

Neijenhuis et al. (2002) assessed auditory closure using different speech stimuli in the presence of noise. When monosyllabic words were presented monaurally in the presence of speech noise, significant age effects were found between children and adolescents, but not between adolescents and adults. Specifically, age effects were found up to 12 years of age. When more complex sentence stimuli were used instead of monosyllabic words, age effects were evident between adolescents and adults. This test showed age effects from 14 years to adulthood. These results suggest that auditory processing of more complex stimuli takes longer to mature than simple single word stimuli (Neijenhuis et al., 2002). Stollman et al. (2004) found significant age effects on all tests included in a behavioral APD test battery with the exception of a monosyllabic speech in noise test. These researchers executed a longitudinal study of children from age 6 to 12 years. When presented with CVC words in the presence of noise at various signal to noise ratios (SNR), scores did not improve with age in a clear maturational pattern. The authors noted, however, that sentence stimuli would have likely produced clear age effects with poorer performance of younger children due to a lack of developed auditory processing, linguistic, and cognitive skills (Stollman et al., 2004).

Binaural interaction.

Binaural interaction can be assessed using a Masking-Level Difference (MLD) test. This task involves the binaural presentation of stimuli and noise in which the phase relationship between the stimuli and the masking noise is manipulated (Wilson, Moncrieff, Townsend, & Pillion, 2003). A comparison is then made between the binaural test conditions to determine the MLD. Speech detection MLD test paradigms have been found to be sensitive to lesions of the lower brainstem in the pontomedullary region (Lynn, Gilroy, Taylor, & Lesier, 1981). In normal hearing young adults, a 500 Hz MLD paradigm is expected to produce an MLD $\geq$ 10 dB (Wilson et al., 2003). Use of this test protocol has also been used to assess auditory processing abilities of children. For example, Hall and Grose (1990) found that MLDs in 26 children between 3.9 and 9.5 years were correlated with age. Using a 500 Hz stimulus tone with a 300 Hz-wide noise band centered at 500 Hz, MLDs increased until 5 to 6 years of age at which time they reached levels comparable to the adult control group. In this test condition, both interaural timing and amplitude cues were present. In a second test condition using a 40 Hz-wide masker stimulus centered at 500 Hz, either timing or amplitude interaural cues were present. In this test condition, the MLDs of the 5 to 6 year old children were slightly below adult MLD values. The age effect observed for the younger children was attributed to the difficulty of less developed central auditory systems in the recognition of interaural cues (Hall & Grose, 1990). Other researchers found no effect of age on the performance of children. For example, Roush and Tait (1984) found no significant age effects in a control group of 18 children between the ages of 6 and 12 years. Masking level differences for this sample of children using 500 Hz tonal and narrowband noise stimuli were comparable to adults, ranging from 10 and 14 dB with a mean MLD of 12.2 dB (SD = 1.1; Roush & Tait, 1984).

Another test of binaural interaction is the Rapidly Alternating Speech Perception (RASP) Test (Willeford & Bilger, 1978). Sentence material is presented in a rapidly alternating pattern between the ears, requiring the listener to integrate the stimuli into a cohesive message (Bellis, 2003). Binaural fusion (BF) tests have also been used as a measure of binaural interaction. This test paradigm involves the presentation of a portion of the speech stimulus to each ear. For example, monosyllabic words may be presented in a sequential manner with consonants to one ear and vowels to the other ear (Bellis, 2003). The clinical utility of the RASP, BF, and MLD tests is questionable as more sensitive measures of brainstem integrity such as the ABR are clinically available (Bellis, 2003).

Test Scoring and Interpretation

Percent correct scores are used to interpret results of most behavioral auditory processing tests as opposed to age equivalencies, percentile rankings, and standard scores (AAA, 2010). Norm-based interpretation is the most commonly used method of test interpretation (ASHA 2005a). This involves the comparison of a child’s performance on a behavioral test to the performance of an age-appropriate normative sample on the same test (ASHA, 2005a). It is generally accepted that a score on a single test that falls within two SDs of the normative sample mean is within normal limits (Kelly, 2007). In order to be classified as indicative of an APD, scores greater than 2 SDs below the mean on two tests are generally required (AAA, 2010; ASHA, 2005a). If a child's score on only one test in the battery falls outside of the accepted cut-off score, this test should be re-administered (ASHA 2005a; Kelly, 2007). In this case, a stricter criterion of 3 SDs below the mean upon re-administration of the single test is considered evidence of an APD (ASHA, 2005a; Kelly, 2007). Moncrieff and Wilson (2009) caution that a diagnosis of APD should not be based on a child's performance on a single test in the battery. Instead, following the cross-check principle of Jerger and Hayes (1976), administration of a different test that measures the same underlying auditory process should be considered. Using this cross-check method reduces the likelihood that decreased performance on a test is due to extraneous non-auditory factors such as fatigue or attention rather than an auditory processing deficit (Moncrieff & Wilson, 2009). Behavioral test results should also be interpreted in combination with the case history findings for the most efficient diagnosis (AAA, 2010).

Statement of Purpose

An efficient behavioral test of auditory processing with high sensitivity and specificity only has clinical utility if appropriate normative data are established (AAA, 2010). If this information is not available, clinicians are encouraged to obtain age-appropriate normative data on each behavioral test administered clinically (AAA, 2010; Emanuel, 2002; Windham et al., 1986). Gender-specific normative data are not included in this recommendation as significant performance differences between males and females have not been reported (Jensen & Neff, 1993; Keith, 2000a; Moncrieff & Wilson, 2009; Stollman, van Velzen, Simkens, Snik, & van den Broek, 2003; Stollman et al., 2004).The purpose of gathering normative auditory processing data is to differentiate between normal and abnormal auditory processing abilities. Because of this, the results of most behavioral APD tests are more accurately reported as a percent correct rather than a percentile or standard score (AAA, 2010). The purpose of this study is to gather normative data on a concise, yet comprehensive behavioral test battery of auditory processing that uses low linguistic content. Data will be analyzed separately in different age groups due to significant maturational effects seen in auditory processing from 7 to 12 years. A comparison between genders will be made to determine whether gender-specific normative data is needed. The test battery will also incorporate measures of language, attention, phonological processing, and intelligence as these factors have been found to influence auditory processing tests results.

CHAPTER 3

Methods and Materials

Participants

Typically developing children between the ages of 7, 0 and 12, 11 voluntarily participated in this study as part of a research study at Towson University in Baltimore, Maryland. Children were recruited from local elementary and middle schools using methods such as postings in school bulletins and recruitment flyer delivery, and by word of mouth. Initial exclusion criteria included hearing loss, a non-verbal IQ of less than 80, English as a second language, and history of language, learning, or reading disorder. The parent or guardian of any child interested in participating in this study completed a comprehensive case history form prior to testing (see Appendix A). Parental consent (see Appendix B) and child assent (see Appendix C) were also obtained prior to testing. The total estimated time of the test battery was 4 hours. The children were given the option to complete the testing in two 2-hour sessions either conducted on the same day (with a lunch break in between sessions) or on different days separated by a maximum of one week to account for potential maturational changes between test sessions. Children were given frequent breaks and the opportunity to discontinue testing at any time. Upon completion of the entire test battery, each participant received monetary compensation in the form of a $30.00 gift card. Approval from the Institutional Review Board (IRB; approval number 10-A035; see Appendix D) was obtained for this study. All testing was conducted by an audiologist and/or graduate student.

Peripheral Hearing Assessment

Prior to performing the auditory processing assessment, a comprehensive peripheral hearing assessment was conducted to ensure normal peripheral hearing sensitivity. A biologic listening check was performed of the equipment prior to each test session. All audiologic testing was performed in a soundproof test suite. The peripheral assessment included a pure tone hearing screening at 15 dB HL across octave frequencies from 250 to 8000 Hz in each ear using EARTONE 3A insert earphones coupled to a GSI-61 Audiometer. Word recognition testing was administered monaurally at 55 dB HL via monitored live voice of Central Institute for the Deaf (CID) W-22 word lists, presenting 25 words to each ear to generate a percent correct score. Acoustic immittance measures, including tympanometry and ART testing, were performed using a GSI TympStar. Tympanometry was performed using a 226 Hz probe tone and results were interpreted according to the Jerger classification system (Jerger, 1970). Ipsilateral and contralateral ARTs were obtained for all participants at 500, 1000, and 2000 Hz. Thresholds were identified as the stimulus level that produced a reflex magnitude of at least 0.02 ml with growth observed at the following stimulus intensity. Acoustic reflex threshold results were interpreted using normative 90^{th} percentile cut-off values (Gelfand, Schwander, & Silman; 1990). Thresholds were assumed to be absent at a maximum presentation level of 110 dB HL. In this case, 115 dB HL was used for data analysis. Transient evoked otoacoustic emissions were tested in both ears from 1000 to 4000 Hz using the ILOv6 to evaluate the functioning of the outer cochlear hair cells. Transient evoked otoacoustic emissions were considered present if the SNR was at least 3 dB at 1000 Hz and 6 dB from 1400 to 4000 Hz.

Auditory Processing Assessment

A total of six behavioral tests were administered to each participant including the Frequency Pattern Test (FPT; Musiek, 1994), Duration Pattern Test (DPT; Musiek, 1994), Random Gap Detection Test (RGDT; Keith, 2000b), Dichotic Digits Test (Musiek, 1983), Compressed (45%) and Reverberated (0.3 s) Northwestern University Auditory Test No. 6 (NU-6) words (Wilson, Preece, Salamon, Sperry, & Bornstein, 1994), and 500 Hz tone Masking Level Difference (MLD; Wilson et al., 2003). These tests were selected in order to assess the underlying auditory processes of dichotic listening, monaural low redundancy, temporal processing, and binaural integration. The order of presentation of the behavioral auditory processing tests was randomized across participants. All testing was conducted in a double-walled soundproof test suite. Test materials were administered using a GSI-61 Clinical Audiometer coupled to EARTONE 3A insert earphones. All auditory stimuli were presented at a comfortable listening level for a normal hearing listener. Test stimuli were obtained from commercially available CDs. Recorded test stimuli for the DDT, FPT, DPT, and CRW tests were located on the Veterans Administration (VA) CD, Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 2.0, and the RGDT and MLD test stimuli were available from Auditec, Inc. Compact discs were calibrated prior to each use. A summary and comparison of the six tests included in the behavioral auditory processing assessment can be found in Table 1.

Frequency Pattern Test.

The FPT presents various pitch sequences of high (H) frequency (1122 Hz) and low (L) frequency (880 Hz) tones of 150 ms duration with an ISI of 150 ms. Each sequence consists of three tones for a total of six pitch combinations: LLH, LHL, HHL, HLH, HLL, or LHH. Five items were given as practice items. A total of 15 test items were presented to each ear. The participant responded by verbally stating the pitch pattern heard using the words “high” and “low.” One or more errors in a sequence were considered incorrect. Reversals (i.e. LHL instead of HLH) were noted on the score sheet, but counted as incorrect (Musiek, 1994). A percent correct score was calculated per ear. This test was administered at 60 dB HL.

Duration Pattern Test.

The DPT presents 1000 Hz tones of varying duration. Short tones (S) are 250 msec and long tones (L) are 500 msec. Each duration sequence consists of three tones for a total of six possible combinations: LLS, LSL, SSL, SLS, SLL, or LSS. Five items were given as practice items. A total of 15 test items were presented to each ear. The participant responded verbally by describing the duration pattern using the words “short” and “long.” One or more errors in a sequence were considered incorrect. Reversals were noted on the score sheet, but counted as incorrect (Musiek, 1994). This test was administered at 60 dB HL.

Random Gap Detection Test.

The RGDT presents pure tone pairs with ISI of 0, 2, 5, 10, 15, 20, 25, 30, and 40 msec (Keith, 2000b). The pairs of tones with varying ISI are each presented at 500, 1000, 2000, and 4000 Hz with ISI in random order. The test was presented binaurally at a comfortable listening level (60 dB HL). The practice track on the RGDT, which presents tones with increasing ISI from 0 to 40 ms, was administered to each child to ensure that he/she could perform the task prior to test administration. The participant responded verbally by saying “one” (to indicate that one tone was heard) or “two” (to indicate that two tones were heard). The lowest ISI (gap) that was consistently detected was recorded for each frequency level as the gap detection threshold. A composite gap detection score was calculated as the average of the thresholds obtained at each stimulus frequency. A minimum of three consistent trials was required to calculate an average gap detection threshold.

Dichotic Digits Test.

The DDT presents two digits (1-10, with the exception of 7) to each ear simultaneously; however, the same digits are never presented to both ears at the same time. The recording is of a male speaker. The participant was asked to verbally repeat all four digits in any order. The participant was given five practice items prior to beginning the test. The remaining 20 pairs of digits were administered binaurally. The scorer kept track of separate ear scores so that a total percent correct score could be calculated per ear (each digit is worth 2.5%). This test was administered at 60 dB HL.

Compressed and Reverberated Words.

The CRW test presents monosyllabic NU-6 words with 45% compression and 0.3 s reverberation. The word lists are spoken by a female. The participant was instructed to verbally repeat the words and guessing was encouraged. Twenty five test items were administered to each ear at a presentation level of 60 dB HL. Percent correct scores were obtained for each ear.

Masking Level Difference.

The MLD test consists of two experimental conditions and one control condition (Wilson et al., 2003). The experimental conditions contain 10 homophasic stimuli (SoNo) and 10 antiphasic stimuli (SπNo), and the control condition contains 11 narrowband noise bursts without tonal stimuli. The listener was instructed to respond by saying “yes” to indicate when he/she heard the pulsing tone within the noise and “no” when a pulsing tone was not heard within the noise. A total of 33 test items were presented. This test was administered binaurally at 70 dB HL using the CD version of the test available from Auditec, Inc. The MLD is calculated by subtracting the SπNo threshold from the SoNo threshold (Wilson et al., 2003).

Table 1

Summary of Auditory Processing Test Battery

Test	Presentation Level[a]	Stimuli	Presentation Mode	Process Assessed	Task
FPT	60	880 Hz (low) or 1122 Hz (high) 150 ms tones	Monaural	Temporal processing (temporal patterning)	Verbally state pattern of 3 tones (low and high)
DPT	60	250 ms (short) or 500 ms (long) 1000 Hz tones	Monaural	Temporal processing (temporal patterning)	Verbally state pattern of 3 tones (short and long)
RGDT	60	Pairs of 500, 1000, 2000, and 4000 Hz tones with random ISI from 0 to 40 ms	Binaural	Temporal processing (temporal resolution)	Verbally state whether one or two tones were heard
DDT	60	Digits 1-10 (excluding 7) Male speaker	Binaural	Dichotic listening (binaural integration)	Repeat all 4 numbers in any order
CRW	60	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
MLD	70	Bursts of NBN within which a series of 5 tone pulses may or may not be present	Binaural	Binaural interaction	Indicate (yes or no) whether tone pulses were heard within the noise

Note. [a] = presentation level in dB HL; 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; MLD = Masking Level Difference; NBN = narrowband noise

Other Assessment Measures

The following additional assessments were performed to better categorize and quantify the normative sample of children in this study. All tests of cognition, language, phonological processing, and sustained attention were administered in a quiet room with minimal ambient noise. The order of administration of the tests was randomized across participants.

Cognition.

The Test of Nonverbal Intelligence, Third Edition (TONI-3; Brown, Sherbenou, & Johnsen, 1997) was used to provide an estimate of each child's non-verbal cognitive functioning through the completion of pattern tasks. The child responded by pointing to the picture that completed the pattern in the picture book. Directions were followed exactly as written in the test manual. A standard score was derived for each participant based on his/her age in years, months. If a child had a non-verbal IQ of less than 80, he/she was excluded from the data analysis.

Language.

The Clinical Evaluation of Language Fundamentals, Fourth Edition (CELF-4; Semel, Wiig, & Secord, 2003) screening test was used to evaluate receptive and expressive language abilities. The CELF-4 screening test contains a total of seven subtests that are administered depending on the child's age. Some of the subtests require the use of an accompanying picture book. Directions were followed exactly as written in the test manual. A total score was derived for each participant based on the number of items correct and compared to the criterion score based on his/her age in years, months. If a child had a total score of less than the criterion score, he/she was excluded from the data analysis.

Phonological processing.

Core subtests (I through VI) of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) were used to assess phonological processing abilities of the participants. The subtests assess the processes of phonological awareness, phonological memory, and rapid naming. Directions were followed exactly as written in the test manual. Based on raw subtest scores, an age equivalent, grade equivalent, percentile score, and standard score were determined. A composite score for each of the phonological processes assessed was also calculated. Composite scores of 90 or greater were considered within normal limits, as specified by the test manual. If a child had a composite score of 90 or below, he/she was excluded from the data analysis.

Sustained attention.

The Integrated Visual and Auditory Continuous Performance Test (IVA-CPT; Sanford & Turner, 2000) assesses sustained auditory and visual attention using a combined visual and auditory task. This test was administered to each participant using a Dell laptop computer. The child's task was to click the external mouse whenever the number '1' was seen or heard. The number '2' was used as a foil. The IVA-CPT has a total of 500 trials with the numbers presented in a pseudo-randomized order. An auditory and visual attention standard score is generated. Directions were followed exactly as written in the test manual. If a child had a standard score of less than 80, but fell within normal limits on all other tasks, he/she was included in the data analysis.

Data Analysis

Data were analyzed using descriptive statistics and Multivariate Analysis of Variance (MANOVA) to evaluate any variance in the behavioral auditory processing test scores between the age groups, genders, and ear scores. A regression analysis was performed to determine if non-verbal IQ scores as measured by the TONI-3 had an effect on auditory processing test performance. Results were considered significant if $p < 0.05$.

CHAPTER 4

Results

A total of 32 children between the ages of 7, 0 and 12, 11 participated in this study. Data from five of these participants (3 males, 2 females) were excluded from the analysis for one or more of the following reasons: below average phonological processing based on one or more CTOPP composite scores of less than 90 (n = 2), inability to complete a behavioral test of auditory processing (n = 1), severely to extremely impaired scores on the IVA-CPT combined with other low test scores (n = 2), and/or auditory processing test scores that were significantly below previous published normative data currently being used clinically at the Towson University Speech, Language & Hearing Center (n = 4). Data from the remaining 28 participants (12 males, 16 females) were analyzed using Microsoft Excel 2010 and SPSS PASW Statistics version 18. Participants ranged in age from 7.0 to 12.25 years (M = 10.0, SD = 1.73). The 28 participants were divided into three age groups, 7-8 year olds (n = 9, M = 7.98, SD = 0.51), 9-10 year olds (n = 8, M = 9.74, SD = 0.59), and 11-12 year olds (n = 11, M = 11.84, SD = 0.45). With respect to gender, there were 4 males and 5 females in the 7-8 year old group, 4 males and 4 females in the 9-10 year old group, and 4 males and 7 females in the 11-12 year old group. Twenty six participants (92.86%) spoke English only, and 2 participants (7.14%) were fluent in both English and Spanish with English spoken as their primary language. Nineteen children (67.86%) played at least one musical instrument, and two of these children (7.14%) played two musical instruments. The vast majority of children in the sample (n = 27; 96.43%) were right handed. Twenty three children (82.14%) had a history of ear infections, and three participants (10.71%) had a history of bilateral pressure equalization (PE) tubes. Other reported medical conditions included seasonal allergies (n = 5; 17.86%), food allergies (n = 2; 7.14%), and ADHD managed with medication (n = 1; 3.57%). Four participants (14.29%) had reportedly undergone an adenoidectomy and tonsillectomy, and one (3.57%) underwent an adenoidectomy only. With respect to birth and delivery complications, four participants (14.29%) had a history of a neonatal intensive care unit stay, six (21.43%) were jaundiced at birth, and one (3.57%) was cyanotic at birth.

Peripheral Hearing Assessment

All participants had normal peripheral hearing sensitivity bilaterally as measured by a pure tone hearing screening at 15 dB HL across octave frequencies from 250 to 8000 Hz. Monaural word recognition testing at 55 dB HL yielded average word recognition scores (WRS) of 99% and 98.57% for the right and left ears, respectively. Twenty six children (92.86%) had Jerger Type A tympanograms bilaterally, one child (3.57%) had Type A_D tympanograms bilaterally, and one child (3.57%) had a Type A tympanogram in one ear and a Type A_D tympanogram in the other ear. Means and standard deviations for each ART stimulus condition are found in Table 2 (ipsilateral ARTs) and Table 3 (contralateral ARTs). This information is also displayed graphically in Figure 1 (ipsilateral ARTs) and Figure 2 (contralateral ARTs). Means and standard deviations for TEOAE SNRs for the right and left ears are found in Table 4. Average TEOAE data by age group is also represented graphically in Figure 3 (right ear) and Figure 4 (left ear).

Table 2

Mean Ipsilateral Acoustic Reflex Thresholds by Age Group

	Right Ear			Left Ear		
Age Group	500 Hz	1000 Hz	2000 Hz	500 Hz	1000 Hz	2000 Hz
7-8 years	88.89 (4.17)	87.78 (2.64)	90.00 (5.59)	90.56 (6.35)	88.33 (7.50)	88.89 (8.94)
9-10 years	89.38 (5.63)	89.38 (7.29)	88.13 (6.51)	95.00 (8.45)	93.13 (7.99)	93.13 (9.98)
11-12 years	91.36 (6.36)	90.00 (7.07)	92.73 (9.58)	92.27 (4.10)	90.00 (5.92)	92.27 (6.07)

Note. Means are reported in dB HL; Standard deviations are in parenthesis

Table 3

Mean Contralateral Acoustic Reflex Thresholds by Age Group

	Stimulus Right Ear			Stimulus Left Ear		
Age Group	500 Hz	1000 Hz	2000 Hz	500 Hz	1000 Hz	2000 Hz
7-8 years	97.22 (7.55)	96.67 (7.91)	96.11 (8.58)	99.44 (6.35)	94.44 (3.91)	96.11 (6.01)
9-10 years	101.25 (8.76)	96.88 (9.23)	96.88 (10.33)	101.88 (7.04)	96.88 (7.53)	95.00 (9.64)
11-12 years	98.64 (7.78)	98.18 (8.74)	97.27 (8.76)	97.27 (9.05)	94.09 (7.01)	95.91 (6.64)

Note. Means are reported in dB HL; Standard deviations are in parenthesis

Figure 1. Mean Ipsilateral Acoustic Reflex Thresholds by Age Group

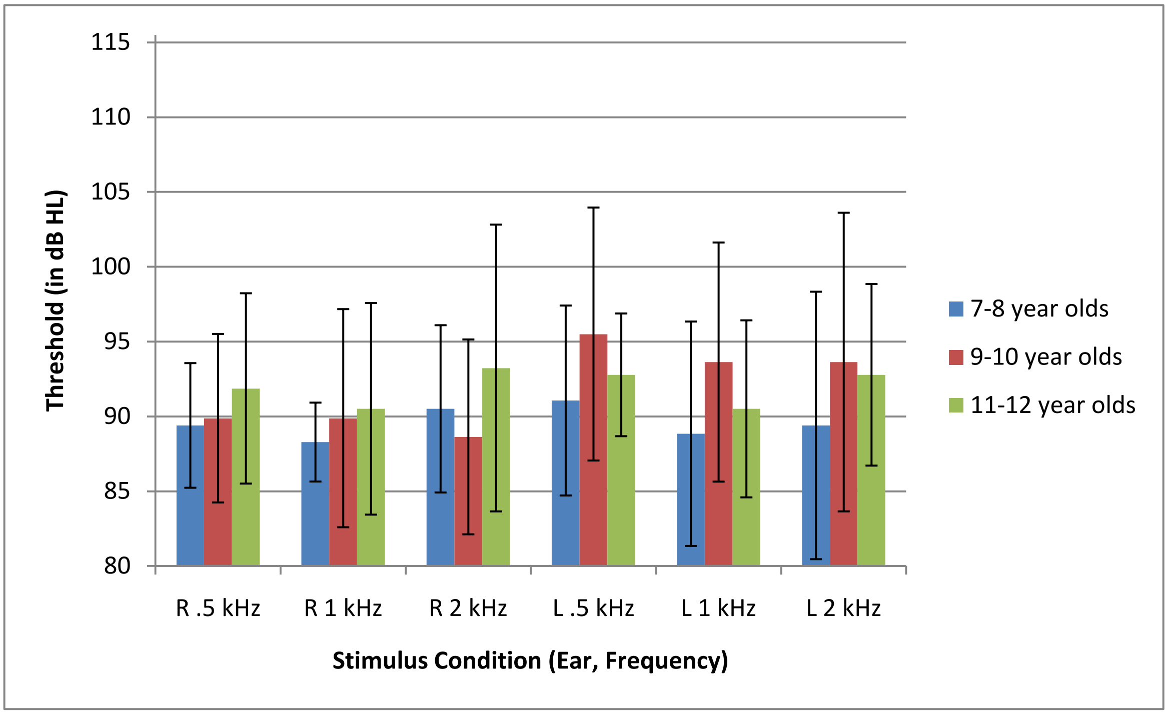

Figure 1. Error bars represent one SD above and below the mean; ART = Acoustic Reflex Threshold; R = right ear; L = left ear

Figure 2. Mean Contralateral Acoustic Reflex Thresholds by Age Group

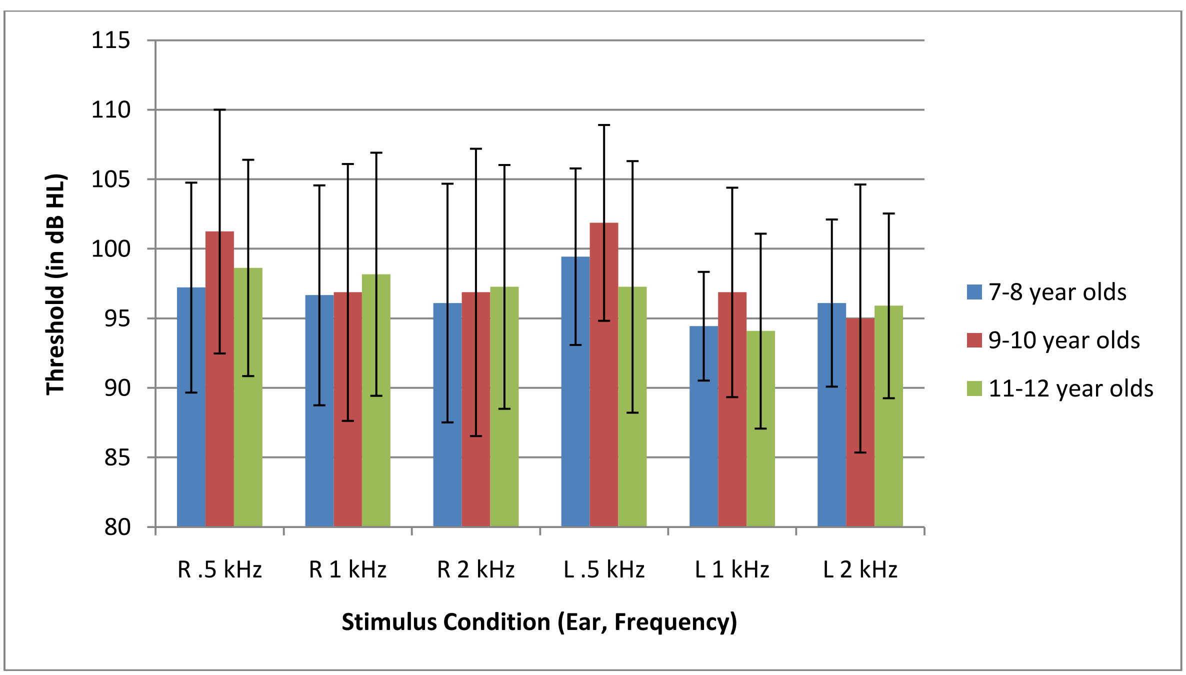

Figure 2. Error bars represent one SD above and below the mean; ART = Acoustic Reflex Thresholds; R = right ear; L = left ear

Table 4

Mean Transient Evoked Otoacoustic Emissions by Age Group

Age Group	Right Ear				
	1000 Hz	1400 Hz	2000 Hz	2800 Hz	4000 Hz
7-8 years	5.68 (5.18)	10.61 (7.47)	13.79 (6.63)	11.52 (5.65)	9.86 (2.78)
9-10 years	9.49 (5.37)	13.39 (5.61)	12.09 (6.03)	9.31 (2.76)	5.20 (5.09)
11-12 years	12.75 (5.30)	17.55 (4.96)	14.93 (5.16)	12.49 (8.94)	6.83 (9.54)
	Left Ear				
	1000 Hz	1400 Hz	2000 Hz	2800 Hz	4000 Hz
7-8 years	5.87 (6.76)	10.59 (6.86)	12.77 (5.92)	13.08 (5.14)	11.53 (5.00)
9-10 years	8.81 (4.31)	13.09 (3.01)	10.83 (6.55)	8.88 (7.00)	4.91 (4.38)
11-12 years	13.18 (4.84)	17.55 (4.69)	16.07 (5.72)	12.52 (6.84)	9.85 (9.49)

Note. Signal to Noise Ratios are reported; Standard deviations are in parenthesis

Figure 3. Mean Transient Evoked Otoacoustic Emissions for the Right Ear by Age Group

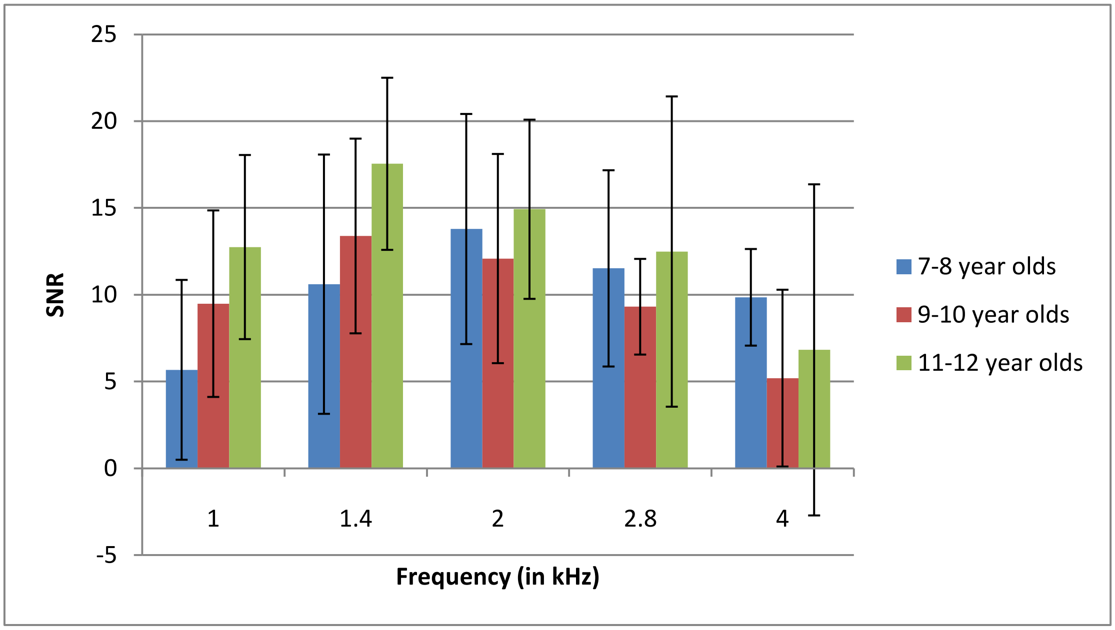

Figure 3. Error bars represent one SD above and below the mean; TEOAE = Transient Evoked Otoacoustic Emissions; SNR = Signal to Noise Ratio

Figure 4. Mean Transient Evoked Otoacoustic Emissions for the Left Ear by Age Group

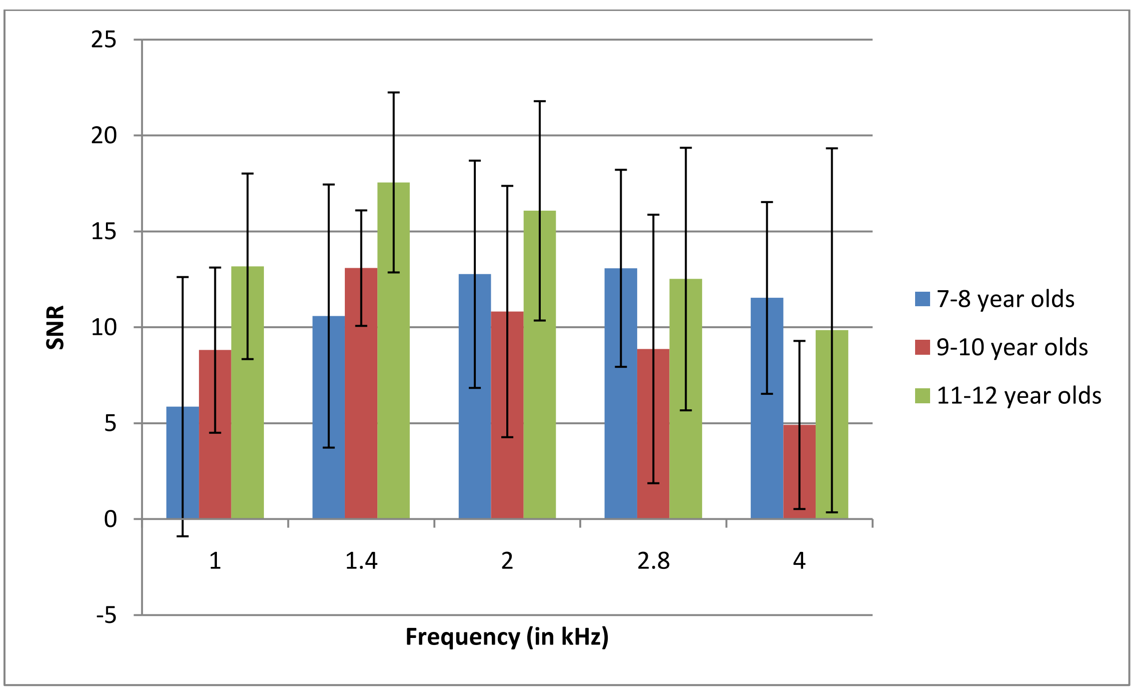

Figure 4. Error bars represent one SD above and below the mean; TEOAE = Transient Evoked Otoacoustic Emissions SNR = Signal to Noise Ratio

Other Assessment Measures

All participants passed the language screening using the CELF-4. Non-verbal intelligence scores as measured by the TONI-3 indicated mean quotient scores of 117.32 (SD = 14.57) for the group, 116.22 (SD = 15.6) for the 7-8 year olds, 120.13 (SD = 13.1) for the 8-9 year olds, and 116.18 (SD = 15.8) for the 11-12 year olds. The results of a multiple regression analysis using SPSS PASW Statistics version 18 indicated that performance on the auditory processing tests was not a significant predictor of nonverbal IQ score as measured by the TONI-3 quotient score, R sq = .372, $F(10, 27) = 1.01$, $p = 0.48$. The phonological processes of phonological awareness, phonological memory, and rapid naming were within normal limits for all participants included in the data analysis as evidenced by CTOPP composite scores of 90 or greater. Of the participants included in the data analysis, one participant scored below average for the auditory and visual domains of the IVA-CPT, and another scored below average for the auditory domain only. These two participants were not excluded from the data analysis as their auditory processing test scores were comparable to previously published normative data (Bellis, 2003) and they passed all other assessment measures included in the test battery.

Auditory Processing Assessment

Ear effects.

In order to analyze ear effects for the monaurally scored auditory processing tests, a difference score was computed for the FPT, DPT, DDT, and CRW test by subtracting the left ear scores from the right ear scores for each participant. A multivariate analysis was performed using the ear difference scores as the dependent variable in order to determine if the difference scores were significantly different overall or by age group.

The results indicated that the overall model was not significant for the entire group, $F(4,24) = 1.75$, $p = 0.17$, or by age group, $F(8,44) = 1.57$, $p = 0.16$. These results suggest that right ear and left ear scores were not significantly different on the FPT, DPT, DDT, and CRW test for the entire group or in any of the age groups.

Age effects.

A MANOVA was performed using SPSS PASW Statistics version 18 to determine if statistically significant differences existed between mean auditory processing test scores of the three age groups. Right ear and left ear scores were analyzed separately for the FPT, DPT, DDT, and CRW test. Due to the wide variability in MLD scores across participants, these results were not considered valid and are not discussed in terms of statistical analysis. Using Wilks' statistic, there was an overall significant effect of age group on the auditory processing test scores, $\lambda = 0.133$, $F(20, 32) = 2.795$, $p = 0.005$. The observed power was 98.1% and the effect size was 0.636. Pairwise comparisons revealed statistically significantly differences between the age groups on the FPT (right ear scores), DPT, and DDT. No significant age effects were found on the FPT (left ear scores), RGDT, or CRW test. Auditory processing test scores are displayed graphically by age group for each of these tests in Figures 5 through 9. For all figures, error bars represent one standard deviation above and below the mean.

A statistically significant age effect was found on the FPT for right ear scores only with the 11-12 year old group scoring significantly higher than the 7-8 year old group ($p = 0.021$). The mean percent correct scores for the right ear were 95.76% (SD = 5.39) and 76.30% (SD = 23.12) for the 11-12 year olds and 7-8 year olds, respectively. The 9-10 year olds scored an average of 90.83% (SD = 11.24) for the FPT right ear, which was not statistically different from the other age groups. No significant differences were found between the age groups for FPT left ear scores. The mean percent correct scores were 77.04% (SD = 24.29), 90.83% (SD = 7.07), and 91.52% (SD = 8.99) for the 7-8 year olds, 9-10 year olds, and 11-12 year olds, respectively. This data is represented graphically in Figure 5.

Figure 5. Frequency Pattern Test Results

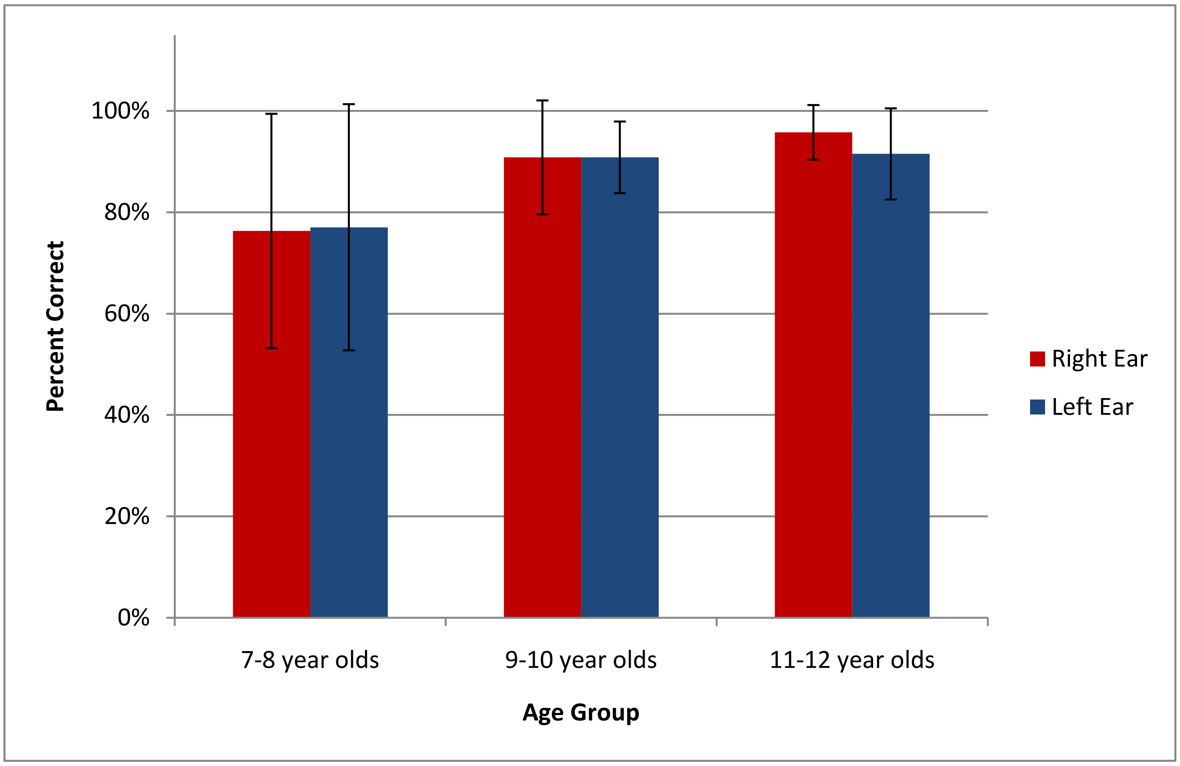

Figure 5. Mean percent correct scores (out of 15 test items) for the right ear and left ear on the Frequency Pattern Test displayed by age group. Error bars represent one standard deviation above and below the mean.

Statistically significant differences were found on the DPT for both right ear scores and left ear scores. The 7-8 year olds scored significantly lower than both the 9-10 year olds (right: $p = 0.004$; left: $p = 0.002$) and the 11-12 year olds (right and left: $p = 0.00$); however, no significant differences were found between the 9-10 year olds and 11-12 year olds ($p > 0.05$). Average percent correct scores for the right ear were 54.82% (SD

= 24.22) for the 7-8 year olds, 81.67% (SD = 8.55) for the 9-10 year olds, and 90.30% (SD = 7.52) for the 11-12 year olds. Average percent correct scores for the left ear were 57.04% (SD = 21.37) for the 7-8 year olds, 84.17% (SD = 11.24) for the 9-10 year olds, and 89.09% (SD = 8.58) for the 11-12 year olds. This data is represented graphically in Figure 6.

Figure 6. Duration Pattern Test Results

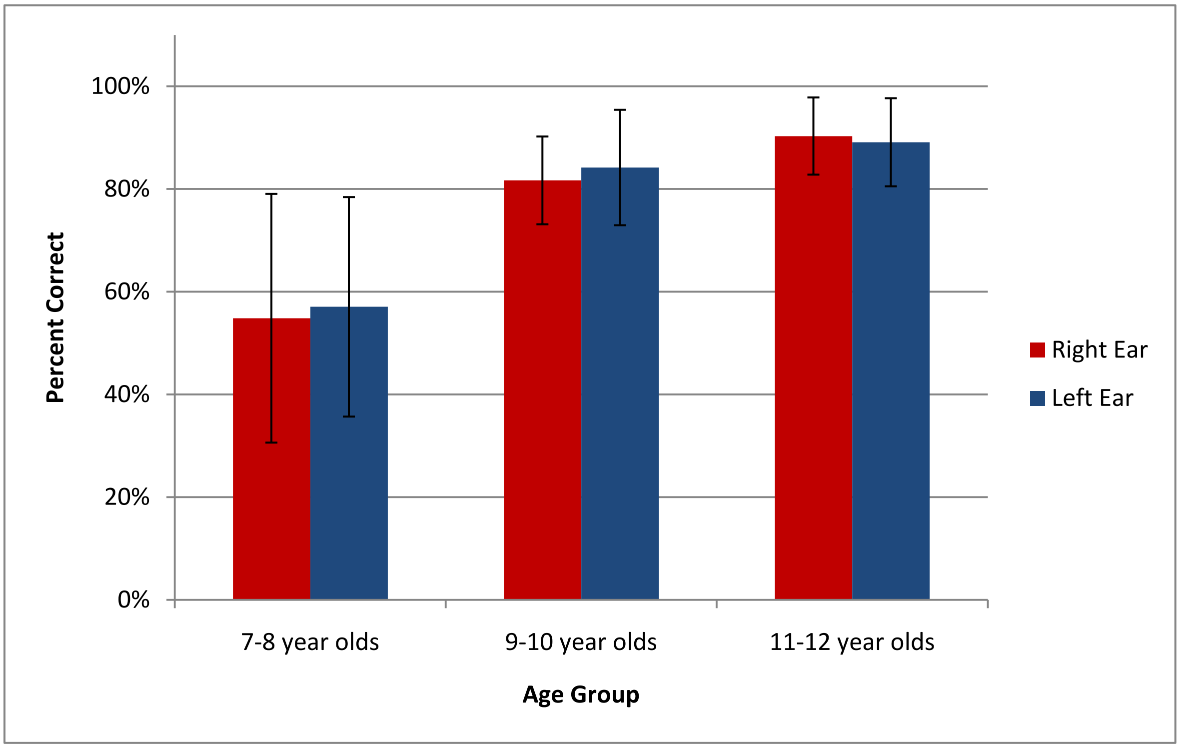

Figure 6. Mean percent correct scores (out of 15 test items) for the right ear and left ear on the Duration Pattern Test displayed by age group. Error bars represent one standard deviation above and below the mean.

Average gap detection thresholds for the RGDT were calculated based on consistent ISI of all four tonal subtests (500, 1000, 2000, and 4000 Hz) for 25 of the participants. For the remaining participants (n = 3), one subtest of the RGDT was excluded due to inconsistent responses. Mean gap detection thresholds were 8.05 ms (SD = 3.83) for the 7-8 year old group, 5.75 ms (SD = 2.33) for the 9-10 year old group, and

6.69 ms (SD = 3.46) for the 11- 12 year old group. No significant differences were found between the average gap detection thresholds between the age groups ($p > 0.05$). This data is represented graphically in Figure 7.

Figure 7. Random Gap Detection Test Results

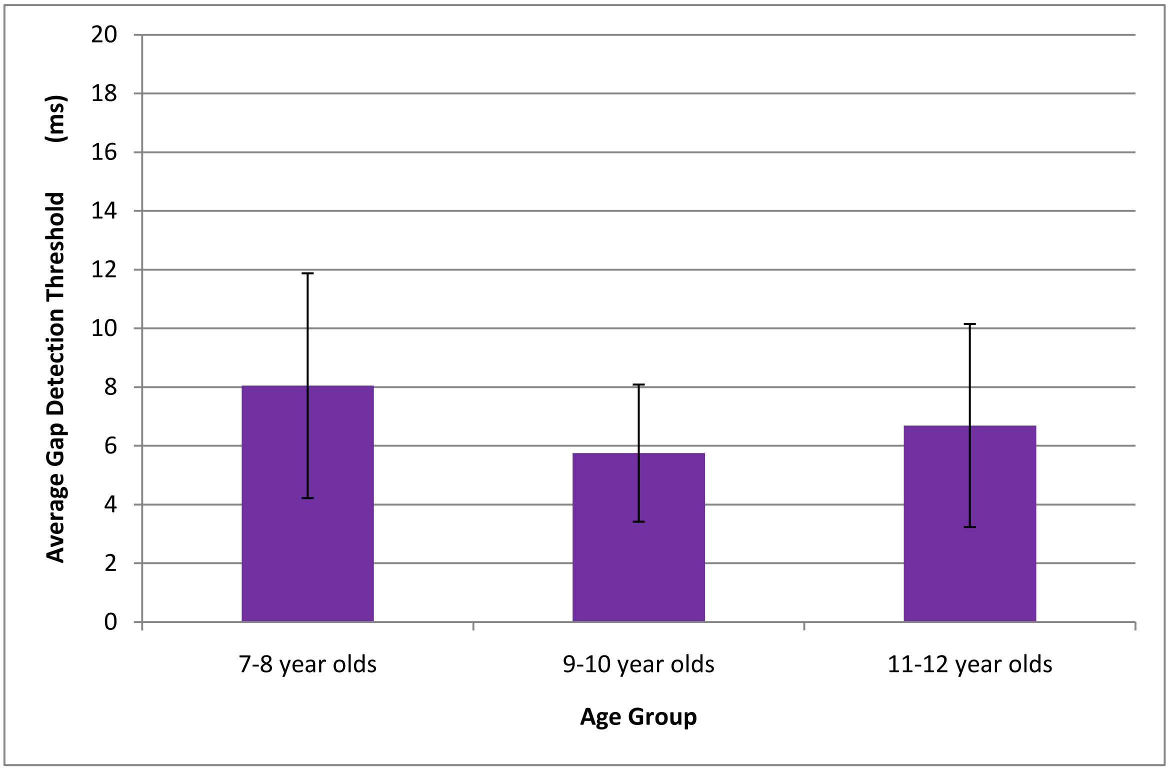

Figure 7. Mean gap detection composite thresholds on the Random Gap Detection Test displayed by age group (based on a minimum of 3 consistent trials for each participant). Error bars represent one standard deviation above and below the mean.

On the DDT, there was a statistically significant difference between the 7-8 year olds and the 11-12 year olds for both right ear scores ($p = 0.003$) and left ear scores ($p = 0.017$), with the oldest group scoring higher than the youngest group. The 7-8 year olds scored an average of 90.28% (SD = 8.43) and 92.22% (SD = 3.41) for the right and left ears, respectively. The 11-12 year olds scored an average of 99.32% (SD = 1.17) and 97.5% (SD = 2.24) for the right and left ears, respectively. Mean percent correct scores of the 9-10 year old group were 96.56% (SD = 4.62) for the right ear and 93.13% (SD =

5.79) for the left ear. These scores were not statistically different from the 7-8 year olds or 11-12 year olds. This data is represented graphically in Figure 8.

Figure 8. Dichotic Digits Test Results

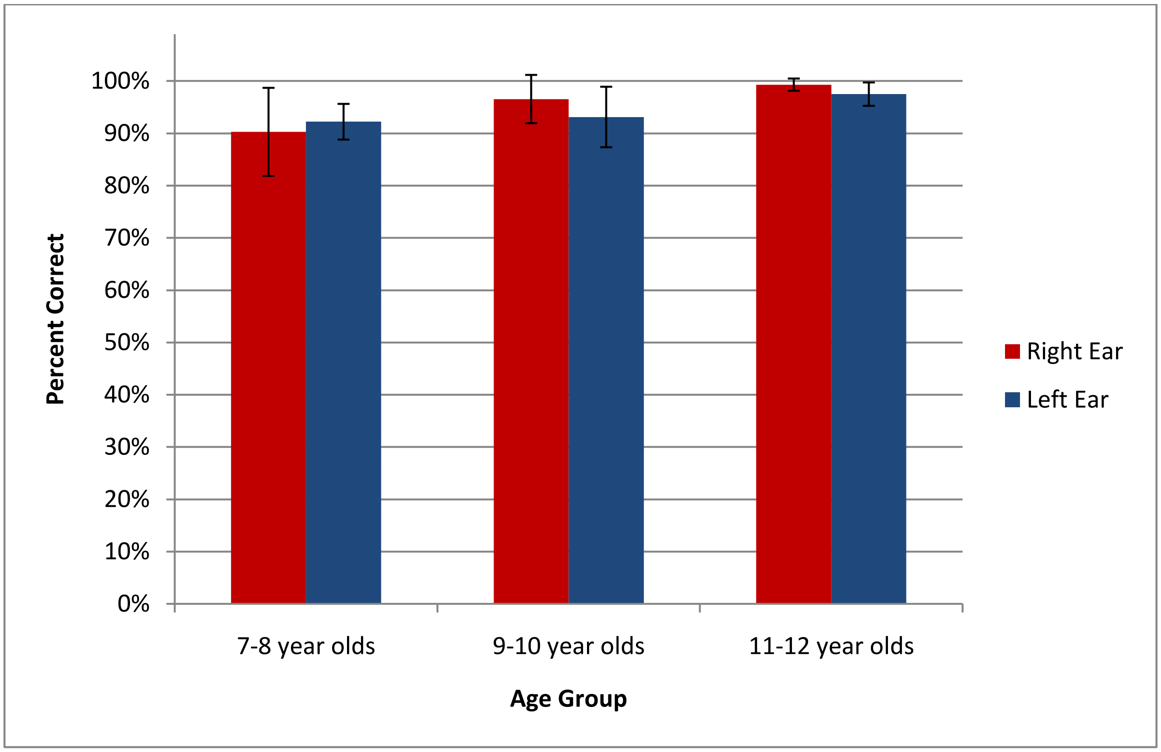

Figure 8. Mean percent correct scores (out of 20 test items, or 40 digits, presented to each ear) for the right ear and left ear on the Dichotic Digits Test displayed by age group. Error bars represent one standard deviation above and below the mean.

Scores on the CRW test were not significantly different between the age groups (*p* > 0.05). This finding was true for both right ear and left ear scores. Mean right ear percent correct scores were 62.22% (SD = 10.60), 62.00% (SD = 14.18), and 69.82% (SD = 8.65) for the three age groups from youngest to oldest. Mean left ear percent correct scores were 56.44% (SD = 9.04), 63.50% (SD = 5.83), and 61.45% (SD = 9.169) for the three age groups from youngest to oldest. This data is represented graphically in Figure 9.

Figure 9. Compressed and Reverberated Words Test

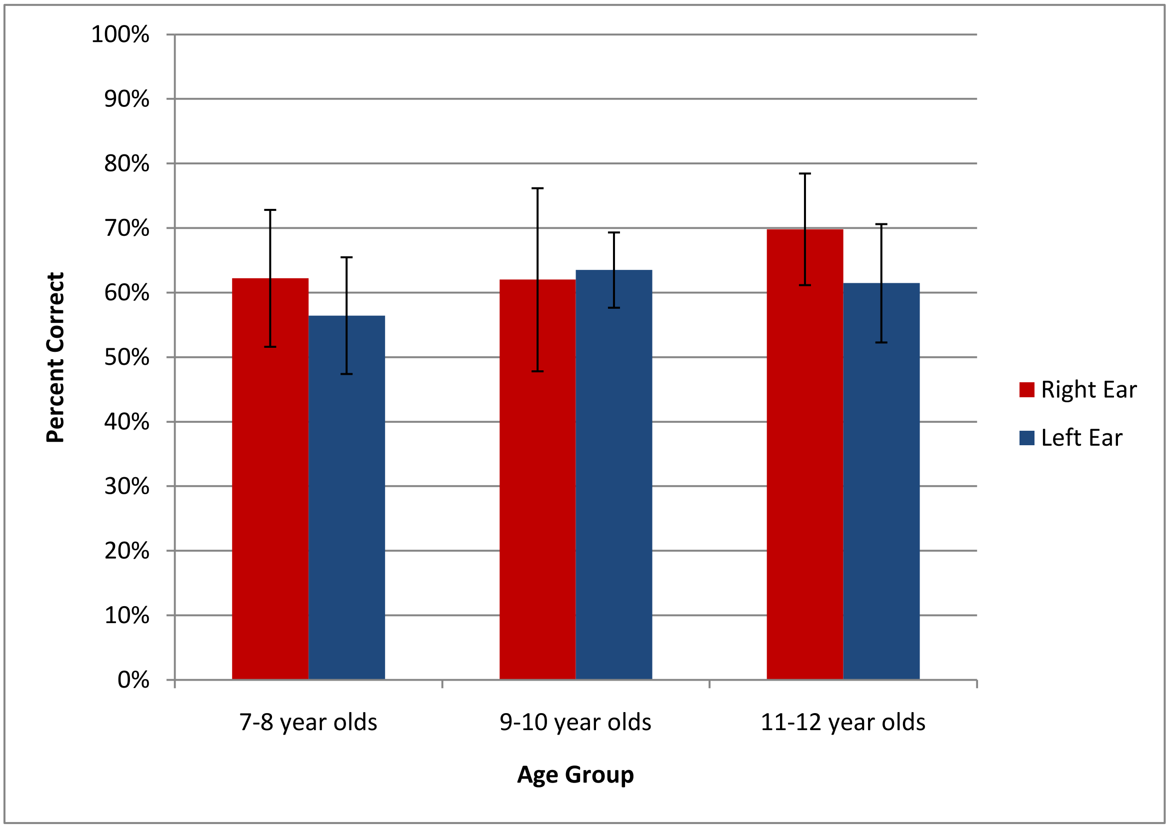

Figure 9. Mean percent correct scores (out of 25 test items presented to each ear) for the right ear and left ear on the Compressed and Reverberated Words test displayed by age group. Error bars represent one standard deviation above and below the mean.

Due to the lack of a statistically significant difference between right and left ear scores on the FPT, DPT, DDT, and CRW tests, another MANOVA was performed using an average score for each participant. Average scores were computed by adding the right ear score and left ear score for each test and dividing the sum by two. Using Wilks' statistic, there was an overall significant effect of age group on the auditory processing test scores, $\lambda = 0.001$, $F(4, 22) = 6214.99$, $p = 0.000$. Significant differences were found between the age groups on the FPT, DPT, and DDT. On the DPT, the 7-8 year olds scored significantly poorer than the 9-10 year olds ($p = 0.002$) and the 11-12 year olds ($p = 0.000$). On the FPT, the 7-8 year olds scored significantly poorer than the 11-12 year olds ($p = 0.43$). Similarly, on the DDT, the 7-8 year olds scored significantly poorer than the 11-12 year olds ($p = 0.000$). This pattern of findings is consistent with the findings of the previous MANOVA which analyzed ear scores separately for each of these tests.

Gender effects.

A MANOVA was performed using gender as the fixed factor instead of age. Using Wilks' statistic, there was no significant effect of gender on the auditory processing test scores, $\lambda = 0.583$, $F(11, 16) = 1.041$, $p = 0.458$. These results indicate that auditory processing test performance was not statistically different between male and female participants.

CHAPTER 5

Discussion

The present study investigated the presence of maturational effects on behavioral tests of auditory processing for normal hearing children between the ages of 7 and 12 years. For the FPT, DPT, DDT, and CRW test, right ear and left ear scores were initially analyzed separately, consistent with clinical practice. With respect to maturation, statistically significant differences were found on the FPT (right ear scores only), DPT, and DDT between the age groups. A comparison between right and left ear scores did not reveal significant differences between ear scores for any of these tests. As a result of this finding, a MANOVA was also performed using an average score rather than individual ear scores for the FPT, DPT, DDT, and CRW test. Using this method, similar results were found, with significant differences between the age groups on the FPT, DPT, and DDT. Secondary aims of this study were to determine whether gender or non-verbal IQ scores impacted auditory processing test performance. The results indicated that gender and non-verbal IQ scores did not significantly influence auditory processing test scores. The findings of the peripheral audiologic assessment and each behavioral auditory processing test in the comprehensive battery are discussed below. Additionally, potential confounding factors, study design limitations, and implications for future research and clinical practice are discussed.

Peripheral Hearing Assessment

A requirement for inclusion in the current study was normal peripheral hearing sensitivity as measured by a pure tone hearing screening, WRS, tympanometry, ART testing, and TEAOEs. Although all children passed the pure tone hearing screening at 15 dB HL across octave frequencies and achieved near-perfect word recognition performance, results of the other audiologic tests were not completely “normal” across all participants. Jerger Type A_D tympanograms were accepted for two of the participants (7.14%) as this subtype is frequently associated with scarring of the tympanic membrane (Jerger, 1970). Acoustic reflex thresholds are expected to be present at 95 dB HL or below in normal hearing individuals (Gelfand et al., 1990). Only eight (28.57%) of the participants in this study had ARTs present at 95 dB HL or below at all stimulus conditions. Based on the SNRs specified in the methods and materials, 12 participants (42.86%) had present TEOAEs at all frequencies tested bilaterally. Future normative data research may consider the use of stricter criteria for the identification of normal hearing participants.

Frequency and Duration Pattern Tests

The FPT and DPT were included to assess temporal patterning. Although these tests utilize similar test paradigms and behavioral task demands, they are presumed to assess different underlying auditory processes (Musiek, 1994; Schochat & Musiek, 2006). On the DPT, the 7-8 year olds scored significantly lower than both the 9-10 year olds and the 11-12 year olds; however, no significant differences were found between the 9-10 year olds and 11-12 year olds. This finding was true for both right ear and left ear scores. On the FPT, significant age effects were found for right ear scores only, with the 7-8 year old group scoring significantly lower than the 11-12 year old group. The right ear scores of the 9-10 year olds were not statistically different from the scores of the other age groups. When the FPT scores were analyzed using an average score rather than individual ear scores, the 7-8 year olds scored significantly lower than the 11-12 year olds.

Other studies have also found that performance on the FPT and DPT improves with age from 7 to 12 years (Kelly, 2007; Schochat & Musiek, 2006). Neijenhuis et al. (2002) did not find significant age effects on temporal patterning tests, but attributed this finding to ceiling effects and the large variability of individual scores. For both the FPT and DPT, the current study found that the scores of the youngest age group were more variable (larger standard deviations) than the other age groups, consistent with the literature (Musiek & Chermak, 1994; Neijenhuis et al. 2002; Stollman et al., 2004).

Right ear scores and left ear scores were not statistically different on the FPT or the DPT, consistent with the literature (DeFosse & Pinheiro, 1978; Musiek et al., 1990; Musiek & Pinheiro, 1987; Schochat & Musiek, 2006). In order to decode and verbally label a pitch or duration sequence, involvement of both brain hemispheres and the corpus callosum is required (Musiek, 1994). The signal is processed in the right hemisphere and transferred to the left hemisphere via the corpus callosum for the assignment of a linguistic label (Mukari et al., 2010; Musiek, 1994). Due to the requirement of both hemispheres to successfully complete tasks of temporal patterning, an ear advantage is not expected on the FPT or DPT.

An unexpected finding was that significant age effects were found for the FPT right ear scores only. It has been suggested that the FPT is less challenging than the DPT (Jensen & Neff, 1989; Schochat & Musiek, 2006). The current data appears to support this finding. Compared to the DPT, mean group scores on the FPT were 11.6% and 9.29% better for the right and left ears, respectively. A possible explanation for a lack of significant age effects for the FPT left ear scores may be related to the higher likelihood of ceiling effects on the FPT compared to the DPT, leaving less room for improvement with age. The ear that was tested first was randomized across participants, so it is unlikely that an order effect impacted test performance. Stollman et al. (2004) found significant age effects on both the DPT and FPT; however, age effects were more pronounced on the DPT test compared to the FPT. It is possible that due to the small sample size of the current study, subtle age effects between the groups were not revealed on the FPT left ear scores.

Formal musical training has been found to improve performance on temporal patterning tests (DeFosse & Pinheiro, 1978). DeFosse and Pinheiro (1978) assessed pitch pattern performance using three response modes (manual, humming, and verbal labeling) in a group of musicians and non-musicians. Musicians consistently performed better than non-musicians regardless of the response mode (DeFosse & Pinheiro, 1978). It has been suggested that higher accuracy scores on temporal patterning tests should be expected from musically trained subjects compared to non-musicians (Musiek, 1994). It is possible that the musical training of the 19 participants (67.86%) in the current study positively impacted their performance on the FPT and DPT. Further exploration of musical training and temporal pattern performance is warranted.

Random Gap Detection Test

All participants in this study had mean gap detection thresholds of less than 20 ms which is the suggested upper limit of normal for children and adult listeners (Keith, 2000b). Specifically, average gap detection thresholds did not exceed 13.75 ms for any of the participants in the sample. Additionally, no significant differences were found between the age groups. This is consistent with the findings of Kelly (2007) who reported comparable mean gap detection thresholds across three age groups: 7-8 year olds (n = 38, M = 6.68, SD = 5.20), 9-10 year olds (n = 56, M = 6.12, SD = 3.73), and 11-12 year olds (n = 35, M = 6.35, SD = 3.73). Chermak and Lee (2005) reported a mean gap detection threshold of 4.77 ms (SD = 1.83) for 10 normal hearing children between the ages of 7.2 and 11.7 years (M = 8.7). Average gap detection thresholds did not exceed 7.5 ms for any of the participants. Consistent with other studies reported in the literature, the results of the current study support the normative cut-off value of 20 ms on the RGDT, and suggest that temporal resolution abilities mature to adult levels by 7 years of age.

Dichotic Digits Test

Dichotic listening, specifically, binaural integration, was assessed using the DDT, double digit version. The 11-12 year olds scored significantly higher than the 7-8 year olds for both right ear and left ear scores, with the 11-12 year olds reaching near-perfect percent correct scores for both ears. It has been suggested in the literature that older, school-aged children are likely to reach ceiling performance levels on the DDT using double digits (Moncrieff & Musiek, 2002; Neijenhuis et al., 2002). The lack of a significant difference between the 9-10 year olds and 11-12 year olds on this task may be attributed to ceiling effects. It is likely that increasing the difficulty of the dichotic listening task by using triple-digits rather than a closed set of double digits may have uncovered age effects between all three of the age groups, similar to the findings of Neijenhuis et al. (2002).

A REA is expected on dichotic listening tasks that utilize verbal stimuli, especially for right-handed listeners (Neijenhuis et al., 2002; Wilson & Leigh, 1996). The results of this study did not find a significant REA on the DDT for any of the age groups. Neijenhuis et al. (2002) found that the REA on the DDT was present in all age groups from children to adults; however, greater variability was noted in the difference scores of the children. Wilson and Leigh (1996) assessed the performance of right-handed and left-handed participants on a dichotic consonant-vowel task. Both groups displayed a REA; however, the advantage was larger for the right-handed subjects than for the left-handed subjects. Performance of the left-handed group was more variable between subjects. Ages of the participants in this study ranged from 19-35 years (M = 22.7) in the right-handed group and 11-57 years (M = 30.1) in the left-handed group; however, age effects were not analyzed (Wilson & Leigh, 1996). Even though the majority of participants in the current study were reportedly right-handed (n = 27, 96.43%), a statistically significant ear advantage was not found. A statistical comparison between right- and left-handed participants was unable to be performed as the current study only included one left-handed participant.

The effect of musical training on dichotic listening task performance has also been explored in normal hearing, young adults (Nelson, Wilson, & Kornhass, 2003). Nelson et al. (2003) compared the performance of musicians and non-musicians on dichotic listening tasks using both verbal and non-verbal stimuli. For dichotic listening tasks using verbal stimuli (nonsense consonant-vowel syllables and triple digits), a significant REA was found, with no difference in performance between the musicians and non-musicians. Although the current study did not find a significant REA, these findings suggest that it is unlikely that the musical training of the 19 participants (67.86%) impacted their performance on the dichotic digits task.

Compressed and Reverberated Words

The CRW test was used to assess the auditory process of monaural low redundancy. This study did not find significant differences in percent correct scores between the age groups for the right ear scores or left ear scores. Similarly, no differences were found between the age groups when an average score was used rather than individual ear scores. This finding is consistent with the normative pediatric data reported by Windham et al. (1986). These researchers found comparable performance of children (n = 40) between the ages of 7, 4 and 11, 3 using PB-K words with 30% and 60% time compression; however, the study did not utilize reverberation and was performed in the soundfield. Furthermore, scores were poorer in the 60% time compression condition compared to the 30% time compression condition across all age groups. Other studies have found an improvement in test scores with increasing age (Beasley, Maki, & Orchik, 1976; Kelly, 2007). Beasley et al. (1976) assessed 60 typically developing children between the ages of 3, 6 and 8, 6 and found that scores increased with age and decreased with the addition of greater amounts of time compression. Based on these results, it is possible that increasing the difficulty of the task by increasing the degree of time compression may have uncovered more subtle performance differences between the age groups in the current study. In clinical practice, however, use of 65% compression is not recommended due to the challenging nature of this task, even for normal hearing adult listeners (Bellis, 2003). Using 65% compression and 0.3 s reverberation, Wilson et al. (1994) suggested a normative cut-off value of 34.9% (2 SD below the mean) for normal hearing adults. Administering this test paradigm to children would likely yield floor effects and have limited diagnostic utility.

In a study of normal hearing adult listeners, mean percent correct scores using the test paradigm employed in the current study (45% compression and 0.3 s reverberation of NU-6 words), was 87.4% (n = 40, SD = 7.3; Wilson et al., 1994). In comparison, the scores of the children in the current study on the CRW test were greater than 2 SD below the adult means reported by Wilson et al. (1994). Specifically, mean scores for the entire group of children (n = 28) in the current study were 65.14% (SD = 11.31) for the right ear and 60.43% (SD = 8.53) for the left ear. Bellis (2003) only reported normative data for children 9 years of age and older due to the high variability and floor effects found for younger children. Although statistically significant differences did not exist between the age groups in the current study, the findings of other research described above suggest that the scores of children (7-12 years old) may be statistically different from the scores of adults. The inclusion of teenage or adult participants may have revealed statistically significant age effects on the CRW test.

A significant difference between right and left ear scores was not found on the CRW test, consistent with the literature on normal children (AAA, 2010; Kelly, 2007). It has been hypothesized, however, that a REA may be seen for younger children on the CRW test due to the high linguistic content of the test stimuli (Kelly, 2007). Despite this hypothesis, it is currently accepted in clinical practice to compare individual ear scores on the CRW test to normative data that is not ear-specific (Bellis, 2003; Wilson et al., 1994).

To further increase the likelihood of uncovering true maturational effects on the CRW test, a larger number of participants should be tested in each age group and full 50 word lists should be administered. To increase the number of test items without significantly increasing test duration, the use of phonemic scoring instead of whole word scoring has been suggested (Kelly, 2007).

Masking Level Difference

The MLD test results were not reported due to the extreme variability in test scores across participants, rendering the test results invalid. Individual MLD thresholds ranged from 0 to 18 dB across participants, with no consistent observable pattern across age groups. Hall and Grose (1993) similarly reported large variability in MLD test scores across normal hearing children with a history of OME and accompanying conductive hearing loss. Children in the current study were not excluded based on a history of chronic OME, as long as the child had normal hearing ($\leq$ 15 dB HL across octave frequencies from 250-8000 Hz) at the time of testing. The variable of OME history may have contributed to the wide range of MLD thresholds. Because of this, it is recommended that future normative data research exclude children with a history of chronic OME, PE tube placement, and/or conductive hearing loss.

Unfortunately, audiometers with MLD capabilities are no longer commercially available (Wilson et al., 2003) and stand alone MLD boxes are not widely available to clinicians either. In clinical development of the 500 Hz MLD protocol in adults with normal hearing, no false positive responses were reported with use of their MLD paradigm (Wilson et al., 2003). The current study found a high prevalence of false positive responses, suggesting that the children were often guessing as to whether or not the tone pulses were present. The presence of guessing may have skewed the results and contributed to the extreme variability in MLD scores, and may have been due to the different paradigm used than the one reported by Wilson et al. (2003).

Variability of MLD test scores may have also been due to a calibration error. Accurate MLD results require the use of earphones that are in phase as indicated by the MLD test instructions (Auditec, Inc.). As a biological check of earphone phase, pure tones presented to each ear at equal intensities should be perceived in the head, not at each ear. Although phase was checked periodically throughout the study by the researchers, an issue with earphone calibration cannot be ruled out as a contributing factor to the variability in participant test results.

Other Potential Confounding Variables

Motivation.

Motivation has been found to impact behavioral auditory processing test results in children (Silman et al., 2000). Silman et al. (2000) reassessed children initially diagnosed with APD using a tangible reinforcer that reflected the child’s preferred treat, hobby, or toy. As a result of testing with the favorite reinforcer, the children’s auditory processing scores improved to within the normal range for their age. It was disclosed to the children in the current study that they would be monetarily compensated for their time in the form of a $30.00 gift card. Although all children in the current study received a gift card in the same amount regardless of their performance, disclosure of this reward prior to testing may have impacted their motivation. Based on the findings of Silman et al. (2000), provision of a tangible incentive has the potential to improve auditory processing test performance compared to testing without a tangible incentive.

History of otitis media.

Twenty three children in the current study had a history of ear infections based on caregiver report, and three of these children had a history of PE tube placement. A history of chronic OME has been found to impact the auditory processing abilities of children, even after resolution of the OME (Hall & Grose, 1993; Zumach, Gerrits, Chenault, & Anteunis, 2009). The case history form used in the current study attempted to address this variable by inquiring as to whether the children had a history of ear infections (yes/no), which ear(s) were affected, the age(s) at the time(s) of occurrence, and the number of occurrences. Many caregivers were unable to accurately answer these questions and responded using vague terminology (e.g. “few”) or question marks. It must be taken into consideration that the accuracy of the caregiver report is impacted by memory. Additionally, it is not uncommon for episodes of OME to go undetected in early childhood, especially in the absence of an acute infection, further impacting the accuracy of the caregiver report.

Early episodes of unilateral or bilateral OME have been found to impact auditory performance later in life (Hall & Grose, 1993; Zumach et al., 2009). Children with unilateral or bilateral OME occurring before 2 years of age had poorer speech recognition abilities in noise at school-age than a control group (Zumach et al., 2009). It is possible that other auditory processing abilities requiring the processing of speech under degraded listening conditions (such as the addition of time compression and/or reverberation) may be similarly affected. Likewise, Hall and Grose (1993) found that MLDs for a 500 Hz pure tone stimulus were significantly smaller in children with a history of chronic OME compared to children without a significant otologic history. These research findings suggest that further investigation into the auditory processing performance of normal hearing children with a history of chronic OME is warranted.

Study Limitations

A potential drawback of the current study was the duration of the test sessions. The majority of children (n = 22) were tested in a single test session lasting 3 to 5 hours depending on the number and duration of breaks that were required. Completing the entire test battery in a single test session had the advantages of being easier for scheduling purposes and more convenient for caregivers with respect to transportation and parking. The single test session format, however, was potentially more cognitively and physically taxing on the children, especially the younger children. To counteract for this potentially confounding factor, the researchers provided ample breaks including a longer break for lunch to assist in reducing the effect of fatigue on the test results.

Another drawback of the current study was related to the sample size and composition. Although a total of 33 children were initially tested, data from five participants were excluded, leaving data from 28 children available for statistical analysis. This sample was further divided into three age groups. The exact age of the participants was not taken into consideration as children were categorized according to a 2 year age bracket. A larger sample size would have allowed the children to be divided into more precise age groups. There were an unequal number of participants in each age group with nine participants in the youngest age group, eight participants in the middle age group, and 11 participants in the oldest age group. Furthermore, an equal gender balance was not achieved in the youngest or oldest age groups. Considerations for future research may include recruitment of a larger sample size, gender balance, and division of participants into narrower age bands.

Clinical Implications

Based on the results of this study, some auditory processing test scores are clearly influenced by maturation, with younger children performing more poorly than older children. Overall, this study found significant age effects on the FPT, DPT, and DDT. Contrarily, no age effects were found on the RGDT or CRW test. These findings were true regardless of gender or non-verbal IQ score. In the current study, the commercially available MLD test available through Auditec, Inc. did not contribute valid data and is therefore not recommended for use in a comprehensive auditory processing test battery for children. Instead, other tests assessing binaural interaction may be considered such as an MLD paradigm using speech stimuli rather than tonal stimuli. The results of this study should be interpreted with the potential confounding variables and study limitations in mind. A comprehensive case history should be obtained from a primary caregiver prior to auditory processing test administration in order to identify potential factors that have been found to influence test performance including, but not limited to, attention, musical training, history of otologic conditions, handedness, speech and language abilities, attention, and overall academic performance. For these reasons, auditory processing test scores cannot be interpreted in isolation. To minimize the effects of patient fatigue and to promote optimal performance in a clinical assessment, audiologists should consider the duration of the test session. It is recommended that auditory processing assessments be completed in less than 1 hour (AAA, 2010). In order to comprehensively evaluate auditory processing abilities in children, audiologists should select tests that assess a wide array of underlying auditory skills such as sound localization and lateralization, auditory discrimination, dichotic listening, auditory pattern recognition, temporal processing, and performance with competing or degraded acoustic signals (AAA, 2010; ASHA, 1996; 2005a). With the exception of the 500 Hz MLD test, the comprehensive auditory processing test battery used in this study has clinical utility for children 7 to 12 years of age.

APPENDICES

Appendix A

Case History Form

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's Name: ____

Date of birth:____Age: ________

Home Address: ____

Home phone: ______________________Parent Work or Cell phone: ______________________

Parent/Guardian name(s):____

School & Teacher:____Current Grade: _______

Name of person filling out this form: _____________ Relationship to participant: ____________

I. BIRTH HISTORY

A. Pregnancy and Delivery:

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

   *If yes, please explain:

   ____

   ____

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

____

____

4. Delivery by Caesarian? Yes ____ No ____

B. Neonatal Period (check where appropriate):

1. Normal: Yes ____ No ____
2. Cyanotic (blue): Yes ____ No ____

3. Jaundiced: Yes ____ No ____
4. Neonatal Intensive Care Unit? Yes ____ No ____
5. Other complications? *Yes ____ No ____

*If yes, please explain:

____

____

6. What was the birth weight? ____lbs. ___oz.

7. Were there any feeding problems? Yes ____ No ____

8. 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(s)? ___________________________________

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:__________________________________ comments:____________________________

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 B

Parental Consent Form

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

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

<u>Purpose of the Study:</u>
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.

<u>Procedures:</u>
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.

<u>Risks/Discomfort:</u>
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. 3 of 3

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 C

Informed Assent Form

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

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 D

IRB Approval Letter

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
Towson University Institutional Review Board
wrp

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CURRICULUM VITA

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EDUCATION:

Towson University, Towson, MD

- *Bachelor of Science (B.S.),* May 2008
  Major: Speech-Language Pathology and Audiology
  Minor: Family Studies
  Honors College
  Graduated Summa Cum Laude
- *Doctor of Audiology (Au.D.),* Expected May 2012

WORK EXPERIENCE:

Towson University Speech, Language & Hearing Center

- *Undergraduate Clinician* (Fall '07)
  Provided speech-language therapy to a school-aged client with auditory processing disorder
- *Graduate Clinician* (Spring '09–Fall '09)
  Conducted audiologic evaluations; hearing aid evaluations, fittings, and follow-ups; electrophysiologic testing; and auditory processing evaluations

Research Assistantship (Fall '08–Spring '10)

- Assisted a professor in the audiology department by conducting research related to audiology, editing professional papers, and assisting with research preparation and data collection

Maryland Audiology

- *Graduate Intern* (Spring '09–Summer '10)
  Performed audiologic evaluations, vestibular treatment, and amplification services for patients of all ages at an ENT practice affiliated with St. Agnes Hospital

Healthy Hearing & Balance

- *Graduate Intern* (Fall '10–Spring '11)
  Provide comprehensive audiologic and vestibular services (including all audiologic services for the Carroll County Public Schools) in a private practice setting

PROFESSIONAL ORGANIZATIONS:

National Student Speech Language Hearing Association (Fall '06–Spring '08)
Golden Key International Honour Society (Spring '07– Spring '08)
Student Academy of Audiology, Towson University Chapter (Fall '08–present)

- Position of Secretary ('09-'10 academic year)

Student Member of the American Academy of Audiology (Fall '08–present)

- Attended national conferences in: Charlotte, NC; Dallas, TX; San Diego, CA; and Chicago, IL

Student Member of the Maryland Academy of Audiology (Fall '10–present)

- Attended and volunteered at the 2010 conference