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EVALUATION OF TEST OUTCOME EQUIVALENCY OF DIFFERENT TEST VERSIONS IN ASSESSING FOR AUDITORY PROCESSING DISORDER

by

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A thesis

Presented to the faculty of

Towson University

in partial fulfillment

of the requirements for the degree

Doctor of Audiology

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

Towson University
Towson, Maryland 21252

May, 2016

TOWSON UNIVERSITY
OFFICE OF GRADUATE STUDIES

THESIS APPROVAL PAGE

This is to certify that the thesis prepared by Molly Day entitled Evaluation of Test Outcome Equivalency of Different Test Versions in Assessing for Auditory Processing Disorder has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree Doctor of Audiology.

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Acknowledgments

I would not have been able to complete my thesis without the guidance of my thesis chair, committee members, friends, and family. I would like to express my deepest gratitude to my chair, Dr. Stephanie Nagle, Ph.D., for her incessant guidance, tremendous patience, enthusiastic attitude, and dedication of time. I would also like to thank my committee members, Dr. Jennifer Smart, Ph.D. and Dr. Shannon Palmer, Ph.D., for their support, direction, and oversight throughout the thesis process. I would also like to thank my parents, sister, brother, and nieces who have always supported and encouraged me to pursue my goals. Additionally, I would like to thank my peers and colleagues, Kim Amrod, B.S., and Katie Leitner, B.S., for standing by my side during some of the toughest times.

Abstract

EVALUATION OF TEST OUTCOME EQUIVALENCY OF DIFFERENT TEST VERSIONS IN ASSESSING FOR AUDITORY PROCESSING DISORDER

Molly Day

The assessment of auditory processing disorder (APD) is complicated by many factors. One of these factors is the availability of numerous tests and test versions that are use clinically, in the absence of a standardized test battery. Thus, the purpose of this study was to determine if three different versions of the DD test (Auditec, Audiology Illustrated, and VA) and three different versions of the FP test (Auditec, Audiology Illustrated, and VA), resulted in the same or different performance in older adults, in order to help lessen the ambiguity of APD assessment. The methods of this study included administering the DD and FP test versions, according to published guidelines, to older adults and comparing their scores to published normative data. The data was analyzed using a repeated measures analysis of variance (ANOVA) for each DD test version and each FP test version, in order to compare the mean test scores for each version. The results of this study indicated significant differences across the FP and DD test versions. The VA FP test version and Audiology Illustrated or Auditec DD test versions were recommended for clinical use.

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Key to Abbreviations

AAA: American Academy of Audiology

ABR: Auditory brainstem response

ADHD: Attention Deficit Hyperactivity Disorder

ANOVA: Analyses of variance

ALR: Auditory late response

APD: Auditory Processing Disorder

ASHA: American Speech-Language Hearing Association

Aud. Ill.: Audiology Illustrated

dB: Decibel

dB HL : Decibel hearing level

CANS: Central auditory nervous system

CD: Compact disk

CNS: Central nervous system

daPa: deca-pascal

DD: Dichotic digits

ETSU: East Tennessee State University

FM: Frequency modulated

FP: Frequency pattern

GSI: Grason Stadler

HL: Hearing loss

Hz: Hertz

IPI: Interpattern interval

ISI: Interstimulus interval

M: Mean

MCI: Mild cognitive impairment

MLR: Middle latency response

MMN: Mismatch negativity

ms: milliseconds

n: Number

OAE: Otoacoustic emission

PPS: Pitch pattern sequence

s: seconds

SLUMS: Saint Louis University Mental Status

SD: Standard deviation

SNHL: Sensorineural hearing loss

SPSS: Statistical Package for the Social Sciences

SRT: Speech recognition threshold

VA: Department of Veterans Affairs

VU: Volume unit

Chapter 1

Introduction

Deficits in the peripheral auditory system, as well as deficits in the central auditory nervous system (CANS), can result in audiologic disorders. Individuals who have normal peripheral hearing in conjunction with difficulty understanding speech, especially in difficult environments, have reduced efficiency of the CANS (American Academy of Audiology [AAA], 2010; Jerger & Musiek, 2000). Auditory processing disorder (APD) may be diagnosed in this instance. Auditory processing disorder is a deficit in processing that impacts listening, learning, and speech understanding (American Speech-Language-Hearing Association [ASHA], 1996). A diagnosis of APD is often complicated by many confounding factors including symptom overlap with other disorders (Jerger & Musiek, 2000). For this reason, a multidisciplinary approach to diagnosis and intervention is imperative (ASHA, 1996).

The diagnostic process for APD is complicated by a lack of consensus regarding assessment. There is currently no standard test battery used in assessment of APD; however, it is generally accepted that a minimum test battery approach be utilized, consisting of a comprehensive selection of behavioral measures (AAA, 2010; ASHA, 2005). Behavioral measures should incorporate tests of five auditory processing abilities including (a) temporal processing, (b) monaural low redundancy, (c) auditory discrimination, (d) binaural interaction, and (e) dichotic listening (AAA, 2010; ASHA, 1996, 2005).

Multiple tests are available to assess for deficits in each of the five auditory processing abilities. Within the five test categories, there are numerous test versions that

are published by various researchers and companies in the field of Audiology. It is currently unknown if there is a difference in performance on different test versions, assessing the same auditory processing ability. Thus, the purpose of this study was to determine if three different test versions of two auditory processes (dichotic listening and temporal processing) resulted in contradictory performance in older adults, in order to help lessen the ambiguity of APD assessment.

Chapter 2

Review of the Literature

Hearing, processing, and understanding speech is essential to verbal communication. The ability to process auditory information is complex and is dependent on the integrity and efficiency of the peripheral auditory system, the CANS, and cognitive processes (ASHA, 2005; Chisolm, Willott, & Lister, 2003). The CANS is greatly intricate and relies on numerous anatomical structures and neural pathways in order to function normally (AAA, 2010; Bamiou, Musiek, & Luxon, 2001; Chisolm et al., 2003). When there is an abnormality in this system, APD may result. Auditory processing disorder is commonly defined as a deficit in which the affected individual has speech understanding difficulties despite normal peripheral hearing (AAA, 2010; Jerger & Musiek, 2000). The topic of APD has gained interest over the past several years due to the fact that it often leads to poorer academic achievement in children, affecting 2-5% of school-aged children in the United States; however, the disorder is most prevalent in older adults, affecting over 70% of this population (AAA, 2010; Bellis & Anzalone, 2008; Rosen, Cohen, & Vanniasegaram, 2010). Many organizations and professionals in the field of Audiology have worked towards a consensus regarding the various aspects of this complex disorder (AAA, 2010; ASHA, 1996, 2005; Jerger & Musiek, 2000).

Since the 1990's, several position papers have been published concerning the various aspects of APD; however, ambiguity and controversy remain (AAA, 2010; ASHA, 1996, 2005; Jerger & Musiek, 2000). It is well known that there is a need for further research and clinical guidance in the diagnosis, assessment, and intervention practices of APD (AAA, 2010). One reason that ambiguity surrounds the topic of APD is

due to the complex nature of the disorder and the variability in symptoms that are exhibited from person to person (Jerger & Musiek, 2000).

Presentation and Etiology of Auditory Processing Disorder

Auditory processing disorder results in the reduced efficiency of one or more auditory processes including (a) sound localization and lateralization, (b) auditory discrimination, (c) auditory pattern recognition, (d) dichotic listening, (e) processing of temporal information, and/or (f) understanding speech under less than optimal conditions (AAA, 2010; ASHA, 1996). Symptoms as a result of these impairments are variable. Symptoms may include deficits in (a) understanding speech in noise, (b) understanding rapid or degraded speech, (c) localizing sound, (d) following directions, (e) concentrating, (f) musicality, and/or (g) detecting humor or sarcasm (AAA, 2010; Jerger & Musiek, 2000; Rosen et al., 2010; Shinn, 2012). The symptoms and observed behaviors seen in individuals with APD vary; however, it often appears as though the affected individual has hearing loss (HL) or some other impairment (Jerger & Musiek, 2000).

Auditory processing disorder may be a manifestation of a neurological disorder in some individuals (Bamiou et al., 2001). Initial studies of auditory processing deficits were focused on patients with neurological lesions (Bocca, Calearo, & Cassinari, 1954; Bocca, Calearo, Cassinari, & Migliavacca, 1955; Calearo & Antonelli, 1963). Multiple lesion types, including tumors of the CANS, head trauma/brain injury, seizures/epilepsy, and stroke, among others, have been found to cause APD (Bamiou et al., 2012; Benavidez et al., 1999; Bergemalm & Lyxell, 2005; Carlsson, Weigand, & Stephani, 2011; Elias et al., 2014). An additional cause of deficits in auditory processing abilities is

recognized as delayed maturation of the central auditory pathways (Musiek, Gollegly, & Baran, 1984; Salamy, 1978). In addition, some disorders are recognized as coexisting with APD. These include developmental disorders such as attention deficit hyperactivity disorder (ADHD), language impairments, and/or learning disabilities (King, Lombardino, Crandell, & Leonard, 2003; Sharma, Purdy, & Kelly, 2009). It can be difficult, and often impossible, to differentiate developmental disorders such as these from a pure, single diagnosis of APD.

Comorbidity. As a result of the intricacy of the CANS, and the influence of higher order cognitive processes, individuals with APD may present with additional impairments that can make differential diagnosis difficult (Musiek, Bellis, & Chermak, 2005; Bamiou et al., 2001). According to ASHA (1996):

> For some persons, APD is presumed to result from the dysfunction of processes and mechanisms dedicated to audition; for others, APD may stem from some more general dysfunction, such as an attention deficit or neural timing deficit, that affects performance across modalities (Executive Summary section, para. 6).

Comorbid disorders that have been found to be associated with APD include ADHD, language impairment, reading disorder, learning disability, intellectual disability, and autism (Jerger & Musiek, 2000; Sharma et al., 2009).

Sharma et al. (2009) evaluated the comorbidity of auditory processing, learning, attention, and language disorders in children ages 7-12 years old. More children (47%) had a problem in all three of these areas rather than an independent presence of APD (4%) (Sharma et al., 2009). Attention problems, in conjunction with a diagnosis of APD, were seen in 58% of the children (Sharma et al., 2009). This research further highlights

the importance of assessing language, reading, and attention in addition to auditory processing (Sharma et al., 2009). Due to the heterogeneous nature of APD, a multidisciplinary approach is important to correctly diagnose APD and/or the presence of another disorder, and to assist in formulating the most appropriate intervention strategy (AAA, 2010; ASHA, 2005; Bellis & Anzalone, 2008; Musiek et al., 2005).

Multidisciplinary approach. A multidisciplinary approach to diagnosis is considered essential due to the high likelihood that APD will be accompanied by, or overlap with, other impairments (AAA, 2010; ASHA, 1996, 2005). Comorbidity with language, learning, attention, cognitive, and other developmental disorders is seen so frequently with auditory processing deficits that it is rare to come across a case of pure APD, especially in children; therefore, multi-professional referrals are necessary (AAA, 2010; Witton, 2010). Specifically, audiologists should work closely with speech-language pathologists who are able to assess the receptive and/or expressive language functions that may be associated with APD (ASHA, 1996, 2005; Bellis & Anzalone, 2008). Despite the fact that a multidisciplinary approach is considered best practice, the audiologist is ultimately responsible for assessing and making the final diagnosis of APD.

Assessment Process for Diagnosis of Auditory Processing Disorder

The goals of the assessment process are to identify the auditory strengths and weaknesses of the patient, to determine the presence or absence of an auditory processing disorder, and to determine the best intervention strategy. A standardized method of assessment has yet to be determined; as a result, many audiologists and researchers have proposed their own opinions of the most optimal way to assess for APD (Emanuel, 2002). Variability in the presenting symptoms and etiologies of these individuals is likely one

reason for the lack of a standardized method of assessment. Audiologists are recognized as the professionals responsible for assessment and diagnosis of APD (ASHA, 2005, 2010).

Audiologist scope of practice for auditory processing disorder. The ASHA Scope of Practice states that the practice of Audiology includes providing services for APD (ASHA, 2005). The ASHA (2010) Code of Ethics mandates that "individuals shall engage in only those aspects of the profession that are within their competence, considering their level of education, training, and experience" (p. 3). Assessment and diagnosis of APD is multifaceted and remains ambiguous; therefore, extensive training and continued education are required. An audiologist must collaborate with, and refer to, other professionals in the field if APD testing falls outside of his/her own audiological skills (AAA, 2010). The diagnosis of APD should be made through the use of case history information, observations, and behavioral tests (AAA, 2010). Electrophysiological tests are also sometimes used in the assessment process (AAA, 2010). Variability in the symptoms and etiologies, that individuals with processing deficits present with, influence the assessment processes.

Confounding factors in assessment. There are many factors to consider prior to assessing for and diagnosing APD. It is imperative that a definitive diagnosis is withheld until a comprehensive and appropriate test battery can be completed (AAA, 2010). Factors that can confound test results include peripheral hearing sensitivity, cognitive and developmental age, attention deficits, and speech-language ability (Jerger & Musiek, 2000).

Hearing status. Hearing loss alone can result in poor performance on behavioral measures of APD and lead to an inaccurate diagnosis (AAA, 2010). Most assessments designed to detect APD are adversely affected by peripheral HL; therefore, normative data for test results on individuals with HL is lacking (Fifer, Jerger, Berlin, Tobey, & Campbell, 1983; Neijenhuis, Tschur, & Snik, 2004). Some tests that use simple or non-verbal stimuli, such as digits or frequency patterns (FP), have been shown to provide accurate results in cases of more mild degrees of HL (AAA, 2010; Musiek, 1983; Musiek & Pinheiro, 1987; Musiek, Gollegly, Kibbe, & Verkest-Lenz, 1991).

Musiek and Pinheiro (1987) administered the FP test to 29 participants with sensorineural hearing loss (SNHL) and obtained only three false positive results. Scores did not correlate with the overall degree of the HL, with the degree of HL at a specific frequency, or with the configuration of the HL (Musiek & Pinheiro, 1987). Musiek (1983) administered the dichotic digits (DD) test to 21 participants with SNHL and obtained only one false positive outcome when using an adjusted failure criterion of 80%. In a follow-up study, Musiek et al. (1991) administered the DD test to 30 participants with mild to moderate SNHL and obtained only two false positive outcomes when using the adjusted criterion.

Age. A primary consideration in assessment, especially of children, is the cognitive and developmental age of the patient referred for testing (AAA, 2010). Few reliable tests have been developed for assessment for children under the cognitive age of 7 years due to the wide variability in the development and maturation of the auditory pathways prior to this age (Bellis & Anzalone, 2008; Salamy, 1978). For children under 7 years with suspected auditory processing deficits, screening tests and behavioral

checklists can be administered to determine if early intervention is warranted prior to a formal diagnosis (AAA, 2010).

As previously mentioned, APD is most prevalent in older adults (Bellis & Anzalone, 2008). It is well known that a progressive decline in peripheral auditory sensitivity and speech understanding ability occurs during the natural aging process. A decline in speech understanding ability was previously thought to be entirely attributed to a decrease in auditory sensitivity; however, it is now recognized as a consequence of age-related functional changes in the CANS (Jerger, Jerger, Oliver, & Pirozzolo, 1989). Many researchers have found that, even after accounting for peripheral SNHL and age related reduced cognitive function, the prevalence of APD increases with age (Gordon-Salant & Fitzgibbons, 1999; Humes, Kewley-Port, Fogerty, & Kinney, 2010; Jerger et al., 1989; Stach, Loiselle, & Jerger, 1991; Stach, Spretnjak, & Jerger, 1990; Strouse, Ashmead, Ohde, & Grantham, 1998). Specifically, Stach et al. (1990) determined the prevalence of APD in 700 individuals, ages 50 to 93 years old. The percentage of individuals with results consistent of APD ranged from 17-58% in the 50 to 69-age range, to 72-95% in the 70 to 93-age range (Stach et al., 1990). Results of these studies are significant for the increasing size of the elderly population, which is expected to double by year 2050 (United Nations Department of Economic and Social Affairs, 2013).

Attention deficits. Attention deficit hyperactivity disorder is characterized by attention and listening problems, distractibility, and difficulty following directions (Chermak, Somers, & Seikel, 1998). The symptoms that are characteristic of ADHD overlap with those of APD, making it difficult to determine the presence of one over the other or the coexistence of both conditions (Chermak et al., 1998). Individuals with

ADHD differ from those with APD in that those with ADHD have the ability to process auditory input normally; it is the decreased ability to sustain attention that is impeding their ability to access the auditory information.

Speech and language ability. An evaluation by a speech-language pathologist is recommended prior to assessment given that speech and language ability can affect APD test results (AAA, 2010). Difficulties with reading, spelling, and expressive and receptive language are characteristic of both APD and language impairments; therefore, it is suggested that a language impairment may result in, or coexist with, APD (ASHA, 2005; Jerger & Musiek, 2000; Miller & Wagstaff, 2011). A speech and/or language disorder can confound test results if the individual's responses cannot be properly understood or, alternatively, if the patient does not understand the test instructions. Assessments using simple verbal stimuli (e.g., digits) and/or those not requiring a verbal response (e.g., a hummed response) should be considered as tests to include in the test battery in these cases (AAA, 2010). If a comprehensive assessment seems inappropriate, screening tools to determine the presence of symptoms and behaviors associated with APD can be utilized.

Screening for auditory processing disorder. Screening methods include questionnaires, checklists, and tests that help to identify individuals thought to be at risk for APD. There is not currently an accepted universal screening method (ASHA, 2005). Many audiologists (56%), surveyed by Emanuel, Ficca, and Korczak (2011), reported using questionnaires as a part of the assessment process. Behavioral questionnaires and checklists completed by teachers and/or parents can be used in order to determine the presence of behaviors indicative of an auditory processing disorder. Behavioral screening

tests can also be used to identify at-risk individuals. The SCAN-A: Test for Auditory Processing Disorders in Adolescents and Adults (or SCAN-C for screening children) is the most commonly used screening tool, used by 69% of survey respondents (Emanuel et al., 2011). The results from screening measures are used to determine if the individual should be referred for a diagnostic evaluation (AAA, 2010).

Audiologic evaluation. Prior to APD assessment, an audiologic evaluation should be performed to rule out a peripheral HL. A typical audiologic evaluation includes pure tone air and bone conduction audiometry, speech recognition testing, acoustic reflexes, tympanometry, and otoacoustic emission (OAE) measurements. An audiologic evaluation is necessary to rule out peripheral hearing loss (sensorineural or conductive) and/or auditory neuropathy spectrum disorder (ANSD), which have the potential to negatively impact APD test results. In addition, electrophysiologic measurements are sometimes used for further differential diagnosis.

Electrophysiology. Electrophysiologic tests objectively measure the function of the brainstem up to the cortex (Jewett, Romano, & Williston, 1970; Kraus, Ozdamar, Hier, & Stein, 1982). These measurements are infrequently utilized in the APD assessment process, likely as a result of the lack of an accepted protocol for their use (AAA, 2010; Emanuel, 2002; Shinn, 2012). Electrophysiologic tests that are recognized as having clinical relevance to assist in identifying APD include the auditory brainstem response (ABR), middle latency response (MLR), auditory late response (ALR), and mismatch negativity (MMN) (AAA, 2010; Bamiou et al., 2001; Jerger & Musiek, 2000).

The ABR is limited in detecting APD as it only provides information through the level of the brainstem (Jewett et al., 1970; Shinn, 2012). Specifically, the click-evoked

ABR often results in normal findings in the majority of individuals being assessed for APD (Mason & Mellor, 1984); however, the speech-evoked ABR may hold more promise for higher sensitivity (Banai, Nicol, Zecker, & Kraus, 2005). The MLR provides information regarding the integrity of the primary auditory cortex, an area necessary for auditory processing (AAA, 2010; Kraus et al., 1982). The ALR, including the P300 response, is generated in the temporal-parietal cortex and provides information regarding the integrity of the auditory association areas (AAA, 2010; Knight, Scabini, Woods, & Clayworth, 1989). The MMN has been found to be sensitive in determining the ability of children and adults to process acoustic differences in speech stimuli, allowing for an objective measurement of discrimination ability (Kraus, McGee, Sharma, Carrell, & Nicol, 1992). Despite the lack of a standard protocol and general low usage of these measures, there are many advantages to including them in the test battery. The use of electrophysiological measures is especially advantageous if behavioral testing is inconclusive or cannot be completed or if the site of dysfunction in the CANS is desired (AAA, 2010). Once the presence of peripheral HL, ANSD, and/or a central lesion has been ruled out, the tests that will be included in the test battery need to be selected.

Test battery approach. The assessment process of APD beings with obtaining a thorough and comprehensive case history, which will provide insight to the nature and severity of the disorder, the etiology, and the possible presence of comorbid disorders that may confound test results. Additionally, patient history will assist in selecting the most efficient and appropriate tests to include in the test battery based on the patient's

reported difficulties and behavioral manifestations (AAA, 2010). The APD evaluation must consist of multiple tests that assess all auditory processing skills and levels of the CANS.

The concept of a test battery approach, in order to achieve the highest possible sensitivity and specificity, is widely agreed upon (AAA, 2010; ASHA, 1996, 2005; Jerger & Musiek, 2000; Musiek, Geurkink, & Keitel, 1982; Shinn, 2012). Including more tests will result in a more sensitive test battery; however, if assessment continues for longer than approximately one hour, the listener may become fatigued and inattentive, likely causing the results to be skewed (AAA, 2010; Musiek et al., 1982). Thus, a carefully selected test battery is paramount to making an accurate diagnosis; however, there is not a general consensus as to which tests should be included.

Various researchers and professionals in the field have published their own suggestions on which tests to incorporate in the test battery. According to Jerger and Musiek (2000), a minimum test battery should include a dichotic listening task, a duration pattern sequence task, a temporal gap detection task, the ABR, and the MLR. According to Bellis and Ferre (1999), the test battery should include tests of dichotic speech, monaural low redundancy, temporal pattering, and binaural interaction. Neijenhuis, Stollman, Snik, and Van der Broek (2001) suggested including a words in noise test, a sentences in noise test, a filtered speech test, a binaural fusion test, a DD test, a backward masking test, and frequency and duration pattern tests. Among audiologists, the most commonly used tests include the FP test, DD test, speech in noise test, and the staggered spondaic word test (Emanuel, 2002). Clearly, there is no one agreed upon test battery; however, considering the reliability of the tests that are included is essential.

Reliability of a test is defined as the extent to which the test results are repeatable at different test times (Cameron & Dillon, 2007). Reliability is measured by administering the same test to the same person, at different times, and analyzing the similarity of the results (Cameron & Dillon, 2007). Test-retest reliability depends on many factors including attention, motivation, psychological condition, memory, maturation, experience, and test conditions. Good test-retest reliability, or a high correlation between scores at different test taking times, is difficult to determine for tests of auditory processing due to the lack of data available to make such comparisons (Cameron & Dillon, 2007; Domitz & Schow, 2000). Due to the lack of evidence regarding test performance for some commonly used APD tests, it is recognized that there is a need to develop more accurate tests with confirmed validity, reliability, and efficiency; however, this is made more difficult by the fact that many tests and test versions are currently being used (AAA, 2010).

Tests of auditory processing disorder. There are five main categories of tests used to assess the integrity of the CANS and auditory processes in order to make a diagnosis of APD. Within each of these test categories there are multiple test versions, published by various researchers and companies, for clinical use. The categories include tests of (a) monaural low redundancy, (b) auditory discrimination, (c) binaural interaction, (d) temporal processing, and (e) dichotic listening (AAA, 2010; ASHA, 1996, 2005).

Monaural low-redundancy. The most basic difficulty experienced by individuals with APD is the ability to understand speech in difficult listening conditions (Keith, 1999). Tests of monaural low-redundancy are characterized by the use of a

purposefully degraded speech signal created by adding competing noise, band-pass filtering, time compressing, or adding reverberation in order to reduce the redundancy of the signal (Bellis, 2003). Simple monaural tasks place little demand on the auditory system, even in the presence of a lesion or abnormality, due to the redundancy of the auditory pathways and the redundancy of the acoustic information in speech (Cacace & McFarland, 2005). Decreasing the redundancy of the acoustic information results in a more sensitive test measure (Bocca et al., 1954; Cacace & McFarland, 2005); however, sensitivity and specificity are generally low for this type of test (Farrer & Keith, 1981; Martin & Clark, 1977).

Auditory discrimination. Auditory discrimination is the ability to differentiate between various types of auditory stimuli in regards to frequency, intensity, and duration cues (AAA, 2010; Bellis, 2003). These cues allow the listener to differentiate between speech sounds. Determining the limit of the auditory system's ability to discriminate changes in these cues is accomplished by finding the thresholds for discrimination of the frequency, intensity, or duration of pure tones (Micheyl, Xiao, & Oxenham, 2012). There are currently no commercially available tests of auditory discrimination in Audiology (AAA, 2010).

Binaural interaction. Binaural interaction relies on the function of both ears to work together in order to process intensity and timing differences in acoustic information (ASHA, 2005). The ability to accurately localize, lateralize, and discriminate speech in noise depends on binaural interaction (ASHA, 2005).

The processing of binaural information relies on the information from the left and right ears, and the information from the neural pathways, to integrate (Polyakov & Pratt, 1998). The masking level difference test has been used to assess this auditory processing ability (AAA, 2010; ASHA, 2005).

Temporal processing. Temporal processing involves the ability to evaluate acoustic information over time through the use of temporal resolution, temporal integration, temporal ordering, and masking (ASHA, 2005; Chermak & Lee, 2005). These temporal processing abilities are necessary for rhythm perception, pitch and duration discrimination, phoneme discrimination, and understanding speech in background noise (Chermak & Lee, 2005). Tests of temporal processing are sensitive to detecting cortical lesions and problems affecting interhemispheric transfer (Bellis, 2003; Musiek & Pinheiro, 1987; Musiek, Baran, & Pinheiro, 1990; Musiek, Pinheiro, & Wilson, 1980).

Musiek et al. (1980) demonstrated the effects of interhemispheric dysfunction through the evaluation of three split-brain participants' performance on FP tasks. The FP task was administered twice with two response modes: a verbal response and a "hummed" response. All three participants had significant difficulty verbalizing the pattern; however, when asked to hum the patterns the participants performed within normal limits. For the task requiring a verbal response, the left hemisphere (dominant for speech and language) depended on the right hemisphere (dominant for melodies and tonal contours); however, the absence of interhemispheric transfer prevented the input from reaching the left hemisphere, thereby precluding the patient from correctly verbalizing the pattern. The researchers concluded that FP tasks distinguish perceptual dysfunction

from processing dysfunction and are sensitive to interhemispheric dysfunction (Musiek et al., 1980).

Musiek and Pinherio (1987) demonstrated the ability of temporal processing tests to correctly detect cortical lesions by comparing the performance of three groups of participants with cortical, brainstem, and cochlear lesions on a FP test (Musiek & Pinheiro, 1987). Only 12% of participants with cochlear lesions had abnormal results, 45% of participants with brainstem lesions had abnormal results, and 83% of participants with cortical lesions had abnormal results. The authors concluded that the FP test has high specificity and sensitivity in evaluating cortical versus cochlear lesions (Musiek & Pinheiro, 1987). Additionally, Musiek et al. (1990) confirmed high specificity and sensitivity of a temporal processing test in detecting cortical lesions. They administered a duration patterns test to groups of participants with normal hearing, with SNHL, or with lesions to auditory areas of the cortex (Musiek et al., 1990). Participants with normal hearing and participants with SNHL performed similarly and within normal limits; in contrast, a majority (86%) of participants with cortical lesions had abnormal results (Musiek et al., 1990). One commonly used test of temporal processing is the FP test.

Pinheiro and Ptacek (1971) first introduced the FP test in a study that investigated the perception of auditory patterns made up of white-noise bursts and auditory patterns made up of tone bursts. They found that the tone burst patterns were easier to perceive than noise burst patterns, likely due to the fact that stimulation of the basilar membrane with a tone burst occurs in a more confined location than a noise burst (Pinheiro & Ptacek, 1971). Since this preliminary study, various companies have reproduced the FP test for distribution and clinical use. For all of the following test versions, the patient is

instructed to verbally repeat the tone pattern he/she hears by saying “high” and/or “low” for each tone in the sequence.

A FP test version, designed by Musiek, is available on the Audiology Illustrated (Aud. Ill.) compact disc (CD). This FP test version consists of 60- triad tone burst FPs. Thirty patterns are presented to each ear in a monaural condition. Each tone burst is 150 ms in duration (10 ms rise/fall time) and varies in frequency between a low tone (880 hertz [Hz]) or a high tone (1122 Hz). The interstimulus interval (ISI) is 200 ms and the interpattern interval (IPI) is 7 s (Musiek & Pinheiro, 1987).

Auditec, a company owned by William Carver, provides auditory test recordings. Auditec offers a CD recording of a FP test version referred to as the Pitch Pattern Sequence (PPS) test. Auditec offers a child version and an adult version of the PPS test. For the purposes of this study, the adult version was used. The adult PPS test consists of 120- triad tone burst patterns. Sixty patterns are presented to each ear in a monaural condition. Each tone burst is 200 ms in duration (10 ms rise/fall time) and varies in frequency between a low tone (880 Hz) or a high tone (1430 Hz). The ISI is 150 ms and the IPI is 7 s (Auditec, 2014).

The Department of Veterans Affairs (VA) sponsored the CD recording of a collection of APD tests in 1992 (East Tennessee State University [ETSU], n.d.). This CD is known as the *Tonal and Speech Materials for Auditory Perceptual Assessment Disc*, commonly referred to as the VA- CD (Noffsinger, Wilson, & Musiek, 1994). There is a Disc 1.0 as well as a Disc 2.0, which is essentially a re-issue of Disc 1.0 with some differences (ETSU, n.d.). Disc 2.0 was used for this study. The VA-CD includes a FP test version that consists of 30- triad tone bust patterns. Fifteen patterns are presented to each

ear in a monaural condition (Musiek, 1994). Each tone bust is 150 ms in duration (10 ms rise/fall time) and varies in frequency between a low tone (880 Hz) and a high tone (1122 Hz) (Musiek, 1994). The ISI is 200 ms and the IPI is 6 s (Musiek, 1994).

Dichotic listening. Tests of dichotic listening involve the presentation of stimuli to both ears simultaneously with information presented to one ear being different from the other. The type of stimuli (digits, syllables, or sentences) and the type of task varies depending on the test (Bellis, 2003). The listener is instructed to repeat everything that is heard (in a binaural integration task), to only repeat what is heard in one ear (in a binaural separation task), or to repeat what is heard in one ear first and then repeat what is heard in the other ear (in an ear directed task) (Bellis, 2003). Kimura (1961, 1964) conducted the preliminary studies of the physiology involved in dichotic listening.

Kimura (1961) examined the ability of unilateral temporal lobectomy patients to repeat digits presented dichotically. Patients with a left temporal lobectomy had poorer scores than those who had a right temporal lobectomy. Kimura concluded that the left temporal lobe is likely specialized for the recognition of verbal stimuli. In addition, scores for both groups were poorer for the ear contralateral to the excised temporal lobe. Kimura concluded that the contralateral, crossed pathways from the ear to the cortex are stronger than the ipsilateral, uncrossed pathways. This effect is only observed when there is some competition between the two pathways, such as during a dichotic listening task. Under such circumstances, the stronger contralateral pathways overpower the weaker ipsilateral pathways (Kimura, 1961).

Kimura (1964) evaluated the performance of normal hearing participants on a DD test and a dichotic melodies test to determine the role of the right and left hemispheres in

verbal and nonverbal auditory perception. Scores for the left ear were significantly better than scores for the right ear on the melodies test (nonverbal stimulus). In contrast, scores for the right ear were significantly better than scores for the left ear on the DD test (verbal stimulus). Due to the greater effectiveness of the crossed pathways, melodies arriving at the left ear were more efficiently transmitted to the right temporal lobe, the area important for their perception, than the melodies arriving to the right ear. In contrast, digits arriving to the right ear were more efficiently transmitted to the left temporal lobe, the area most important for their perception, than digits arriving to the left ear. This study supports the view that the right temporal lobe has a greater role in nonverbal auditory perception, and the left temporal lobe has a greater role in verbal auditory perception (Kimura, 1964).

Dichotic listening tests have well known sensitivity to the detection of interhemispheric, cortical, and brainstem lesions and dysfunction (Milner, Taylor, & Sperry, 1968; Shinn, 2012; Sparks & Geshwind, 1968; Stephens & Thronton, 1976). Milner and collogues (1968) found that six split-brain patients were unable to report digits presented to the left ear during a DD test. Sparks and Geschwind (1968) also found that a split-brain patient was unable to report any digits presented to his left ear; however, he was able to report the stimuli presented to his right ear. These preliminary studies revealed the importance of the corpus callosum in transferring information from one hemisphere to the other, dysfunction of which will result in a left ear deficit (Milner et al., 1968; Musiek & Weihing, 2011; Sparks & Geschwind, 1968). Oxbury and Oxbury (1969) found that a left temporal lobectomy resulted in an impaired ability to report digits presented to the right ear; additionally, digits heard in the left ear were reported first more

frequently than digits heard in the right ear. Stephens and Thronton (1976) obtained abnormal DD test results in approximately 40% of the participants with confirmed brain stem lesions. There are several DD test versions available for clinical use.

In a study conducted by Musiek in 1983, the DD test was administered to participants with normal hearing and no history of neurological disease, to participants with confirmed cortical and brainstem lesions, and to participants with SNHL. Normative data was established from the group of normal participants. The DD test was composed of the spoken digits one through ten with the exception of the number seven (as it is multisyllabic). Two digits were presented to one ear, and two digits were presented to the other ear, simultaneously. Based on the data obtained from the normal group, scores below 90% were considered abnormal in the presence of normal hearing. For those with SNHL, scores below 80% were considered abnormal. Using these criteria, 5% of the participants with SNHL, 81% participants with CNS lesions, and none of the normal hearing participants had failing scores. The results from this study suggest that the DD test is sensitive to identifying cortical and brainstem lesions, and has high specificity (Musiek, 1983). Since these preliminary studies, various companies have reproduced the DD test for distribution and clinical use. For all of the following test versions, the patient is instructed to verbally repeat all of the digits he/she hears in any order.

The DD test, designed by Musiek, is available on the Aud. Ill. CD. This CD contains two DD test tracks, one of which consists of 20 one- pair digits, and one of which consists of 20 two- pair digits. The two- pair digits track, used for the purposes of this study, includes randomized two digit pairs including numbers one through ten (with the exception of seven). The ISI is 500 ms and the IPI is 4 ms (Musiek, 1983).

The VA- CD contains four different DD tests that vary by the presentation of 1- pair, 2- pair, 3- pair, or 1- 2- 3- pair digits interleaved randomly. The 1- 2- 3- pair interleaved digit track was used for the purposes of this study. This track contains digits one through ten (with the exception of seven) in 18 1- pair, 18 2- pair, and 18 3- pair sets. The ISI is 500 ms for the one- pair digits and 600 ms for the 2 and 3- pair digit sets. The IPI is 4 s for 1- pair, 5 s for 2- pair, and 6 s for 3- pair digit sets (ETSU, n.d.).

The Auditec CD also contains a DD test version. The test track consists of 50 sets of digits one through ten (with the exception of seven). The digit sets can be presented in single pairs (one digit to each ear) or double pairs (two digits to each ear). The double pair digits track was used for the purposes of this study. The ISI is 800 ms and the IPI is 4 s (Auditec, 2014).

Diagnostic criteria. The FP and DD test versions that have been explained above, are scored similarly. The total number of correct responses is summed and a percent correct is calculated. The individual's score is compared to published or clinically obtained normative data, based on age, to determine if it falls within the normal range. This comparison to normative data is completed for each test in the APD assessment to determine if the diagnostic criterion is met.

The criteria that must be met in order to make a formal diagnosis of APD has been recommended by multiple national working groups, and has been agreed upon as a score that falls at least two standard deviations (SD) below the mean for at least two different auditory processing tests, or more than three SD below the mean on one test in at least one ear (AAA, 2010; ASHA, 2005). Cutoff scores for the tests are developed from studies using the results of normal hearing participants, or can be obtained in-house,

as is often recommended, by individual clinics using normal hearing listeners (AAA, 2010). The performance on the completed tests guides the intervention process.

Intervention for Auditory Processing Disorder

Intervention is geared towards each individual's specific areas of processing deficits. Intervention can consist of auditory training, environmental modifications, preferential seating, compensatory strategies, and/or the use of a frequency modulation (FM) system (AAA, 2010; Bellis & Anzalone, 2008). FM systems are proven to have multiple benefits for individuals with APD including increased attention, improved learning, and enhanced speech recognition in noise (AAA, 2010; Johnston, John, Kreisman, Hall, & Crandell, 2009). To determine if the intervention is effective for a patient, an improvement on his/her auditory processing test results should be noted (AAA, 2010). As making a diagnosis should include a collaborative approach with various professions, so too should intervention (Shinn, 2012). A multidisciplinary team is recommended due to the impact of auditory processing deficits on listening, communication, academic achievement, job performance, and social skills (AAA, 2010). Using a comprehensive test battery that assesses all auditory processing skills, and making an accurate diagnosis, is imperative for the best patient outcomes.

Statement of Purpose

Despite the publication of guidelines and consensus reports, controversy and confusion remain regarding the assessment, diagnosis, and rehabilitation of APD. The governing bodies in the field of Audiology recognize the need for continued research in these areas. The frequent comorbidity with other disorders and the heterogeneous nature of APD contribute to the controversy. Confusion results from the extensive variety of

tests available for assessment in the absence of an effective standardized test battery. This extensiveness in availability of tests is made more overwhelming by the availability of different test versions distributed by various companies. A difference in performance on different test versions has not been studied up to this point. Thus, the purpose of this study was to determine if three different versions of the DD test and three different versions of the FP test, resulted in the same or different performance in older adults, in order to help lessen the ambiguity of APD assessment.

Chapter 3

Methodology

Participants

Thirty adults, between the ages of 55 and 75, were recruited for this study. Prior to testing, Institutional Review Board approval (Appendix A) was obtained and all participants signed an informed consent form (Appendix B). To qualify as a participant pure-tone air-conduction thresholds were ≤ 25 decibel hearing level (dB HL) for octave frequencies between 250 and 2000 Hz and ≤ 50 dB HL for 4000 and 8000 Hz (Humes, Coughlin, & Talley, 1996; Musiek et al., 1991; Musiek & Pinheiro, 1987). Normal (Type A) tympanograms were required and defined as a static compliance of 0.3 ml -1.4 ml, peak pressure within -150 deca-pascal (daPa) to + 100 daPa, and an ear canal volume of 0.6 ml -1.5 ml (Jerger, 1970). Thirty participants, who met these criteria, were included in the study and participated in the following test procedures.

Procedures

All participants were tested through the use of the same equipment, materials, and audiological and behavioral measures. The Saint Louis University Mental Status (SLUMS) exam was conducted with each participant prior to testing, in order to rule out mild cognitive impairment (MCI) or dementia (Appendix C) (Cruz-Oliver, Malmstrom, Allen, Tumosa, & Morley, 2012). Pure-tone air and bone conduction thresholds, and speech recognition thresholds (SRT) were obtained for both ears of each participant using the Grason Stadler (GSI) 61 audiometer and ER-3A insert earphones. A pure-tone audiological evaluation was conducted using the Modified Hughson-Westlake procedure (Carhart & Jerger, 1959). Hearing was assessed at the octave frequencies from 250 to

8000 Hz in both ears, with a push button response mode. Bone conduction thresholds were obtained at 500, 1000, 2000, and 4000 Hz. Tympanometry was completed using a 226 Hz probe tone. The auditory processing tests were administered in accordance with the recommended procedures for each test version; details of which are presented below.

Auditory processing test version administration procedures. Auditory processing tests are pre-recorded on CDs and distributed for clinical use. The Aud. Ill., Auditec, and VA-CDs were used for this study. The order in which each CD, and the FP and DD test tracks within each CD were administered, was randomized for each participant. In addition, the order in which each ear was tested first, for the FP tests, was counter-balanced. Ear order was not applicable for the DD tests since digits are presented dichotically. As an example, tests were administered to Participant 1 in the following order: first, the Auditec CD might be selected randomly with the DD test first, followed by the FP test presented to the right ear first and then the left ear. Second, the Aud. Ill. CD might be selected with the FP test presented to left ear first and then the right ear, followed by the DD test. Third, the VA-CD would be used, with the DD test first, followed by the FP test presented to the left ear first and then the right ear. Prior to testing the first participant, randomization was performed for CD order, test order, and ear order (for FPs). This information was recorded on thirty score sheets. Prior to the start of testing for each CD, the CD was calibrated to the audiometer by adjusting the calibration tone (included on the CD) to peak at zero on the volume unit (VU) meter. The details of administration for each test version are presented below. Refer to Table 1 and Table 2 for summaries of FP and DD test version characteristics, respectively.

Audiology Illustrated frequency pattern test version administration. The FP test, designed by Musiek, is available on the Aud. Ill. CD. The FP test CD track contains 60- triad tone burst FPs. Each tone burst (10 millisecond [ms] rise/fall time) is 150 ms in duration and varies in frequency between a low tone (880 Hz) or a high tone (1122 Hz). The ISI is 200 ms and the IPI is 7 s. Administration, instructions, and practice items were completed in accordance with Musiek and Pinheiro (1987). The researcher informed the participant that he/she would hear sets of three consecutive tones that would be either high pitched or low pitched. The researcher provided visual cues (holding hand at a higher level and then at a lower level) and hummed pattern examples of what high and low pitch stimuli sound like. The participant was instructed to verbally repeat the three-tone pattern that he/she heard, in the same order the tones were presented, by saying "high" and/or "low" for each tone in the sequence. Participants were encouraged to guess if they were unsure of what they heard. The test was administered at 50 dB HL. A random starting pointing on the track was selected and six patterns were presented for practice. Once the researcher was confident that the participant understood the task, the test track was reset and 30 test patterns were presented to each ear in a monaural condition. If the participant needed more time to respond, the CD was paused. Percent correct was calculated for each ear, counting reversals as incorrect (Musiek & Pinheiro, 1987).

Auditec frequency pattern test version administration. The Auditec PPS test consists of 120- triad tone burst patterns; 60 patterns are presented to each ear in a monaural condition. The first ten out of the 60 patterns for each ear are practice; therefore, the test is scored based on 50 patterns for each ear. Each tone burst is 200 ms in

duration (10 ms rise/fall time) and varies in frequency between a low tone (880 Hz) or a high tone (1430 Hz). The ISI is 150 ms and the IPI is 7 s. The test was administered at 50 decibel (dB) sensation level (SL) re: pure tone threshold at 1000 Hz. The researcher instructed participants to verbally repeat the three- tone pattern they heard, in the same order that the tones were presented, by saying "high" and/or "low" for each tone in the sequence. Each ear was scored for percent correct, counting reversals separately but as correct, to obtain a total percent correct score (Auditec, 2014).

VA-CD frequency pattern test version administration. The VA-CD includes a FP test version that consists of 30- triad tone bust patterns. Each tone bust is 150 ms in duration (10 ms rise/fall time) and varies in frequency between a low tone (880 Hz) and a high tone (1122 Hz). The ISI is 200 ms and the IPI is 6 s (ETSU, n.d.). The researcher instructed participants to verbally repeat the three- tone pattern they heard by saying "high" and/or "low" for each tone in the sequence and encouraged participations to guess if they were unsure (Musiek, 1994). The test was administered at 50 dB HL (Musiek, 1994). The researcher provided visual cues (holding hand at a higher level and then at a lower level) and hummed pattern examples of what high and low pitch stimuli sound like. A random starting point on the track was selected and six patterns were presented for practice. The first 15 patterns were presented to one ear and the remaining 15 patterns were presented to the other ear. Each ear was scored for percent correct, counting reversals as incorrect (Musiek, 1994).

Table 1

Summary of Frequency Pattern Test Version Characteristics.

Test version	Items per ear	High & low frequencies (Hz)	Tone duration (ms)	ISI (ms)	IPI (s)	Administration level
Aud. Ill	30	880 & 1122	150	200	7 s	50 dB HL
Auditec	50	880 & 1430	200	150	7 s	50 dB SL re: pure tone threshold at 1000 Hz
VA	15	880 & 1122	150	200	6 s	50 dB HL

Audiology Illustrated dichotic digits test version administration. The DD test, designed by Musiek, is available on the Aud. Ill. CD. This CD contains a track of 20 1- pair digits and a track of 20 2- pair digits. The 2- pair digits track was used for the purposes of this study. Randomized pairs of two digits one through ten (with the exception of seven), were presented simultaneously to each ear via channel one and channel two on the audiometer. The ISI is 500 ms and the IPI is 4 s. The researcher informed participants that they would hear two numbers in each ear at the same time and instructed participants to repeat all of the numbers they heard in any order, and were encouraged to guess if they were not sure. The participants were instructed that the first three items were practice. The test was administered at 50 dB SL re: the participant's SRT. The CD was paused if participants needed extra time to respond. The number of correctly repeated digits was summed and percent correct was calculated for each ear (Musiek, 1983).

VA-CD dichotic digits test version administration. The VA-CD has seven tracks devoted to DD testing. These tracks include the presentation of 1- pair, 2- pair, 3- pair, or 1- 2- 3- pair digits interleaved randomly. The 1- 2- 3- pair digits track was used for the purposes of this study. This track contains digits one through ten (with the exception of seven) in 18 1- pair, 18 2- pair, and 18 3- pair sets that are interleaved randomly without any indication as to how many digits will be in each subsequent set. The digits were presented simultaneously to each ear via channel one and channel two on the audiometer. The ISI is 500 ms for the 1- pair digit set and 600 ms for the 2 and 3- pair digits sets. The IPI is 4 s for 1- pair, 5 s for 2- pair, and 6 s for 3- pair digits sets. The researcher informed participants that they would hear one, two, or three numbers in each

ear at the same time and instructed participants to repeat all of the numbers they heard (whether it be two, four, or six digits), in any order. The test was administered at 50 dB SL re: the participant's pure tone average. The number of correctly identified digits was summed for each condition (1-, 2-, and 3-pair digits), and percent correct was calculated for each ear (Strouse & Wilson, 1999a, 1999b).

Auditec dichotic digits test version administration. The Auditec CD also contains a DD test version. The test track consists of fifty sets of digits one through ten (with the exception of seven). The digit sets can be presented in single pairs (one digit to each ear) or double pairs (two digits to each ear). The two- pair digits track was used for the purposes of this study. The digits were presented simultaneously to each ear via channel one and channel two on the audiometer. The ISI is 800 ms and the IPI is 4 s. The researcher informed participants that they would hear two numbers in each ear at the same time and instructed participants to repeat all of the numbers they heard in any order. The test was administered at 50 dB SL re: the participant's speech recognition threshold. The number of correctly repeated digits was summed and percent correct was calculated for each ear (Auditec, 2014).

Data Analysis

Following data collection, the difference between test scores on the FP test versions and DD test versions was analyzed using the Statistical Package for the Social Sciences (SPSS) version 19 program. Descriptive statistics, pairwise comparisons, Fisher's exact tests, and repeated measures analysis of variance (ANOVA) tests were completed.

The presence or absence of a statistically significant difference in test scores (dependent variable), dependent on the test version (independent variable), was determined. Statistical significance was determined utilizing an alpha level less than or equal to .05.

Table 2

Summary of Dichotic Digits Test Version Characteristics.

Test version	Test items	Stimuli	ISI (ms)	IPI (s)	Administration level
Aud. Ill	20	2- pair digits 1-10 (excludes 7)	500	4	50 dB SL re: SRT
Auditec	50	2- pair digits 1-10 (excludes 7)	800	4	50 dB SL re: SRT
VA	54	1-, 2-, 3- pair digits 1-10 (excludes 7)	500 (1- pair) 600 (2- pair) 600 (3- pair)	4 (1- pair) 5 (2- pair) 6 (3- pair)	50 dB SL re: PTA

Chapter 4

Results

Thirty-four older adult participants were recruited for this study; however, four were excluded as a result of pure-tone thresholds exceeding this study's qualifying levels. Thus, 30 participants (nine males and 21 females) were included in this study for data analysis. Participants ranged in age from 55 to 73 years (M= 62.03 years with SD 5.76 years). All participants met the pure-tone threshold criteria and had normal (Type A) tympanograms.

A majority (83%) of participants fell within the normal range (27-30 points) on the SLUMS screener. The five participants that did not fall within the normal range fell within the MCI range (21-26 points). This included two females and three males ages 58 (n=1), 67 (n=1), 68 (n=2), and 73 (n=1). Fisher's exact tests revealed no significant differences between age or gender and passing status on the SLUMS. Fisher's exact tests were also run to determine if passing status on the SLUMS had an effect on passing status on the FP and DD test versions. Fisher's exact test was significant for passing status on the SLUMS and passing status on the FP VA test version (for both ears).

Descriptive Statistics

There were no significant differences between male and female scores, so all data for gender was collapsed for subsequent analysis. Mean percent correct scores and SD (one SD from the mean) for the right and left ears, for the FP and DD test versions, can be seen in Table 3. For the FP test versions, mean right and left ear scores were highest for Auditec, followed by Aud. Ill., and lowest for VA. For the DD test versions, mean right and left ear scores were similar for Auditec, Aud. Ill., and VA. The scores for the

VA DD test version were calculated according to number of digits (Strouse & Wilson, 1999a, 1999b). Mean scores were highest for 1-pair, followed by 2-pair, and lowest for the 3-pair digits. Mean percent correct scores and SD (one SD from the mean) for right and left ears on the DD and FP test versions can be seen in Figure 1 and Figure 2, respectively.

Table 3

Mean Percent Correct Scores and Standard Deviations for Ears and Test Versions.

	Frequency Pattern			Dichotic Digits				
						VA		
Ear	**Auditec**	**Aud. Ill.**	**VA**	**Auditec**	**Aud. Ill.**	**1-pair**	**2-pair**	**3-pair**
Right	96.13 (7.46)	83.93 (17.21)	77.07 (26.11)	96.43 (4.17)	95.57 (4.58)	98.67 (2.94)	96.83 (4.07)	90.50 (10.33)
Left	95.40 (7.60)	85.50 (17.24)	79.57 (21.94)	91.57 (6.51)	92.87 (8.00)	96.67 (5.62)	91.50 (10.75)	83.80 (13.80)

Note. Standard deviation (one SD from mean) reported in parentheses.

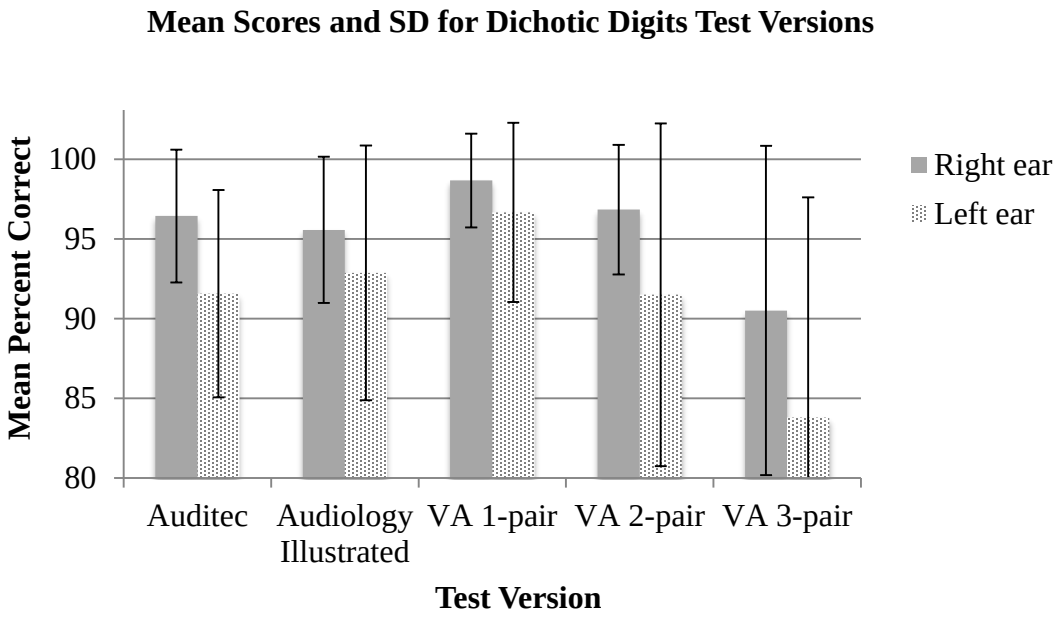

Figure 1. Mean percent correct scores and SD for right and left ears on DD test versions. Right ear is indicated by solid fill, left ear is indicated by patterned fill. Error bars represent 1 SD from the mean.

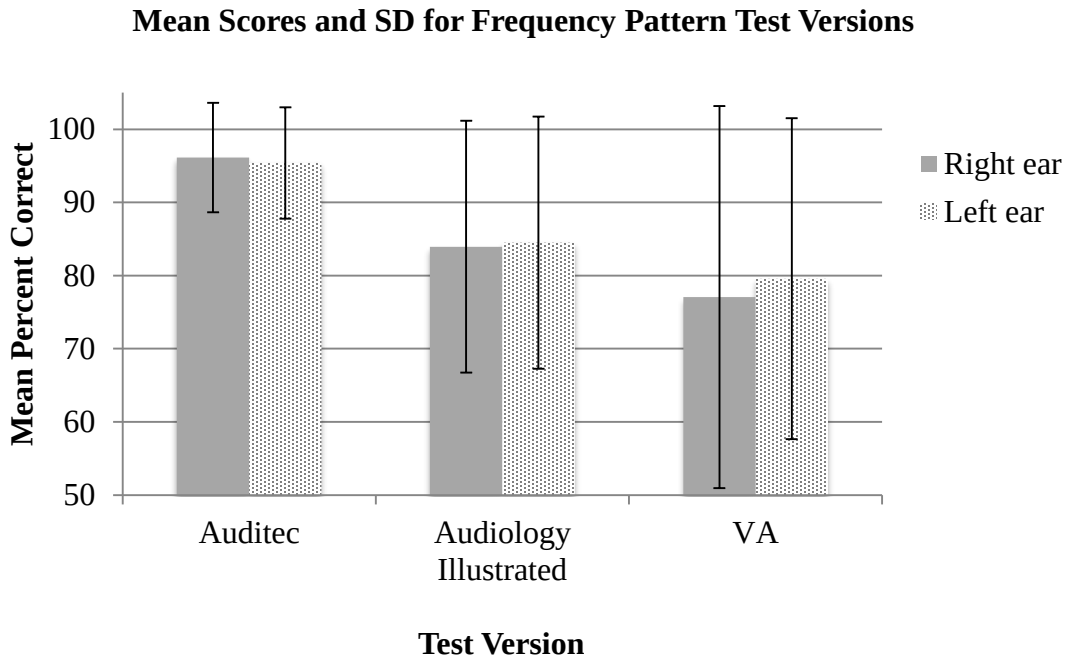

Figure 2. Mean percent correct scores and SD for right and left ears on FP test versions. Right ear is indicated by solid fill, left ear is indicated by patterned fill. Error bars represent 1 SD from the mean.

Effect of Test Version

Statistical analyses were completed to determine if test version had an effect on test score. Repeated-measures ANOVAs and pairwise comparisons were performed.

Frequency pattern test versions. A 2x3 repeated-measures ANOVA was performed to examine the effect of ear (right, left) and FP test version (Auditec, Aud. Ill., and VA) on test score. Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of FP test version, $x^2(2)= 27.77$, $p <.001$; therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. There was a significant main effect of FP test version on test score, $F(1.30,37.65)=24.09$, $p <.001$. There was no significant main effect of ear on test score, $F(1,29)=.77$, $p=.39$, and no significant interaction effect between FP test version and ear, $F(1.42,41.17)=1.12$, $p=.32$.

Post-hoc testing was conducted using the Bonferroni correction for pairwise comparisons of the FP test versions. The significance values for pairwise comparisons of the FP test versions can be seen in Table 4. All pairwise comparisons were significant ($p < 0.05$). Mean test scores and pairwise comparisons indicated that performance was best on the Auditec version, followed by the Aud. Ill. version, and worst on the VA version.

Table 4

Frequency Pattern Test Versions Pairwise Comparisons.

Test Versions Compared	**Sig.**
Auditec vs. Aud.Ill.	<.001*
Auditec vs. VA	<.001*
Aud. Ill. vs. VA	.006*

Note. Sig.= p value. *= $p < .05$

Dichotic digits test versions. A 2x5 repeated-measures ANOVA was performed to examine the effect of ear (right and left) and DD test version (Auditec, Aud. Ill., VA 1-pair, VA 2-pair, and VA 3- pair) on test score. Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of test, $x^2(9)= 23.50$, $p=.005$; therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. There was a significant main effect of test on test score, $F(2.73,79.09)=21.72$, $p <.001$. There was a significant main effect of ear on test score, $F(1,29)=13.41$, $p <.001$, and no significant interaction effect between test version and ear, $F(1.77,51.25)=2.17$, $p=.13$

Post-hoc testing was conducted using the Bonferroni correction for pairwise comparisons for the DD test versions. The significance values for pairwise comparisons of the DD test versions can be seen in Table 5. Results indicated significant differences ($p < 0.05$) between the VA 1-pair digit condition and all other DD versions, and between the VA 3-pair digit condition and all other DD versions. No other pairwise comparisons were significant. Mean test scores and pairwise comparisons indicate that performance was best on the VA 1-pair digit condition, and the worst on the VA 3-pair digit condition. Performance was similar between the VA 2-pair digit condition, Aud. Ill. version, and Auditec version.

Table 5

Dichotic Digits Test Versions Pairwise Comparisons.

Test Versions Compared	**Sig.**
VA 1-pair vs. Aud. Ill	.021*
VA 1-pair vs. Auditec	<.001*
VA 1-pair vs. VA 2-pair	.008*
VA 1-pair vs. VA 3-pair	<.001*
VA 2-pair vs. Aud. Ill	1.000
VA 2-pair vs. Auditec	1.000
VA 2-pair vs. VA 3-pair	<.001*
VA 3-pair vs. Aud. Ill	.001*
VA 3-pair vs. Auditec	.001*
Auditec vs. Aud. Ill	1.000

Note. Sig.= p value. *= $p < .05$

Clinical Significance

In order to determine clinical significance, scores were categorized as “pass” or “fail”. The cutoff criteria for a passing score on the FP test versions were as follows: 78% on the VA version (Musiek, 1994); 75% on the Aud. Ill. version (Musiek & Pinheiro, 1987); 88% on the Auditec version (Auditec, 2014). The cutoff criteria for a passing score on the DD test versions were as follows: 90% on the Aud. Ill. and Auditec versions 90% (Auditec, 2014; Musiek, 1983); varied depending on the number of digits (1-, 2-, or 3-pair) and age of the participant (50-59, 60-69, or 70-79 years) on the VA version (Strouse & Wilson, 1999a). Cutoff criteria for a passing score on the VA DD test version can be seen in Table 6.

Table 6

Lower-bound 95% Confidence Interval for VA Dichotic Digits Test.

	Right Ear			Left Ear		
Age	**1**	**2**	**3**	**1**	**2**	**3**
50-59	95	87	72	90	72	62
60-69	94	88	75	88	77	66
70-79	91	86	73	85	68	57

Note. Percentages indicate the lower end of the 95% confidence intervals calculated from the mean percent correct recognition data for 1-, 2-, and 3-pair digits separated by age group; published by Strouse and Wilson (1999a).

The number (n) of failing scores for right and left ears on each DD test version was subtracted from the number of right or left ears (n=30), and subsequently divided by the number of right or left ears (n=30) to calculate a percentage of the number of participants who fell within normal limits in each ear. The passing rates for right and left ears, for each DD test version, can be seen in Table 7. Half of the participants (n=15) failed at least one DD test version (or at least one VA DD test condition) in at least one ear. Two participants failed all versions in the left ear (no participants failed all versions in the right ear). The test versions that participants failed varied tremendously with no clear pattern observable. A visual representation of these findings can be seen in Figure 3.

The number of failing scores for right and left ears on each FP test version was subtracted from the number of right or left ears (n=30), and subsequently divided by the number of right or left ears (n=30) to calculate a percentage of the number of participants who fell within normal limits in each ear. The passing rates for right and left ears, for each FP test version, can be seen in Table 8. Out of the participants who failed at least one FP test version in at least one ear (n=12), all failed the VA test version in at least one ear and most (n=10) failed the VA version in both ears. Most participants (n= 9) that failed the VA version in at least one ear also failed the Aud. Ill. version in at least one ear. Two participants failed all three versions in both ears. Two participants failed all versions with the exception of the right ear on the Auditec version. Most participants that failed a version in one ear failed the same version in the opposite ear. A visual representation of these findings can be seen in Figure 4.

Table 7

Passing Rates for Right and Left Ears on Each DD Test Version.

			VA		
Ear	**Auditec**	**Aud. Ill.**	**1-pair**	**2-pair**	**3-pair**
Right	100%	90%	86%	93%	80%
Left	73%	77%	90%	83%	90%

Table 8

Passing Rates for Right and Left Ears on Each FP Test Version.

Ear	Auditec	Aud. Ill.	VA
Right	90%	73%	63%
Left	80%	76%	63%

	Left Ear					*Right Ear*				
Participant	**Auditec**	**Aud. Ill.**	**VA**			**Auditec**	**Aud. Ill.**	**VA**		
			1	**2**	**3**			**1**	**2**	**3**
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										

Figure 3. Participants that failed at least one DD test version in at least one ear (n=15). Shaded cells indicate the test(s) that received a failing score. For the VA version, the numbers 1, 2, and 3 indicate the digit condition (1-pair, 2-pair, or 3-pair digits).

	Left Ear			*Right Ear*		
Participant	**Auditec**	**Aud. Ill.**	**VA**	**Auditec**	**Aud. Ill.**	**VA**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

Figure 4. Participants that failed at least one FP test version in at least one ear (n=12). Shaded cells indicate the test(s) that received a failing score.

Chapter 5

Discussion

In this study, three different versions of the FP test (Auditec, Aud. Ill., and VA) and three different versions of the DD test (Auditec, Aud. Ill., and VA) were administered to 30 adults (ages 55-73 years), in order to determine if performance differed based on test version. The tests were administered and scored based on published guidelines and normative data. A comparison of the outcomes for each FP test version and each DD test version will be reviewed in the following sections.

Comparison of Test Version Outcomes

Statistically significant differences in performance were found across the test versions. The possible reasons for such differences in performance were explored.

Frequency pattern test versions. The results from this study revealed that there was a statistically significant difference between all three of the FP test versions. Statistical analyses and mean scores suggested performance was best on the Auditec version, followed by the Aud. Ill. version, and the worst on the VA version. In the present study, none of the FP test versions demonstrated ear effects, which is in agreement with previous findings (Musiek, 1994; Musiek & Pinheiro, 1987).

There are numerous neural processes involved in the recognition and sequencing of frequency patterns. The process of FP discrimination begins with stimulation of the two frequencies along the basilar membrane at two different locations (vonBekesy, 1960). The primary auditory cortex recognizes the two distinct groups of fibers that have high discharge rates, allowing for recognition of the frequency of the sounds (Moller, 1983). The recognition of the contour of the pattern is performed in the right hemisphere

(Blumstein & Cooper, 1974). Prior to the listener sequencing the pattern, short-term memory and retrieval are required (Mukari, Umat, & Othman, 2010). The linguistic labeling of the pattern is processed in the temporoparietal region of the left hemisphere (the area responsible for language processing) (Halperin, Nachshon, & Carmon, 1972). The actual verbal response requires that the interhemispheric pathway is intact for the transmission of the sequenced information to the frontal regions of the brain where the motor response is initiated (Musiek & Pinheiro, 1987). Dysfunction in any one of these necessary hierarchal steps has the potential to impair the ability of the listener to perform well on this central auditory test. The stimuli and test parameters of the FP test influence the processes involved in frequency discrimination and pattern sequencing. These parameters include the frequencies of the high and low tones, the duration of the tones, the ISI, and the IPI. Additionally, the number of items presented to each ear and the acoustical quality of the stimulus recording may have an impact on outcome.

There have been no studies that have examined patient perception of the degree of difficulty on different FP test versions; however, it can be assumed that when the frequencies of the two tones (high and low) are further apart, discrimination is easier. The Auditec FP version consists of a high tone of 1430 Hz and a low tone of 880 Hz- a difference of 550 Hz (Auditec, 2014). In contrast, the Aud. Ill. and VA versions both use a high tone of 1122 and a low tone of 880- a difference of 242 Hz (Musiek, 1994; Musiek & Pinheiro, 1987). In this study, performance on the Auditec version was better than on the Aud. Ill. and VA versions. This is most likely due to easier discrimination based on a larger difference between the high and low tones, a concept that has been confirmed in studies of the MMN event-related potential.

The MMN is elicited by infrequent changes (deviant stimulus) in a sequence of the same (standard) auditory stimulus (Naatanen, 1982). The presence of the MMN indicates that the detection of change has occurred in the auditory cortex (Naatanen, Paavilainen, Tiitinen, Jiang, & Alho, 1993). The amplitude and latency of the response are related to the degree the deviant stimulus differs from the standard stimulus (Alain, Achim, & Woods, 1999). The MMN is associated with behavioral discrimination of the stimulus; therefore, the presence of the response indicates that the listener can discriminate the difference between the standard and deviant stimuli (Naatanen et al., 1993). Stimuli that are not easily discernible elicit small and later MMNs in contrast to stimuli that are easier to discriminate, which elicit large and earlier MMNs (Sams, Paavilainen, Alho, & Naatanen, 1985). Researchers have shown that greater differences in the frequencies of the standard and deviant stimuli result in a larger, earlier MMN indicating easier perceptual discrimination (Alain et al., 1999; Novitski, Tervaniemi, Huotilainen, & Naatanen, 2004). If the frequencies of the tones included on the FP test are not easily distinguishable the listener will have significant difficulty making the conscious decision to classify the tone as “high” or “low”, subsequently impairing his ability to sequence the pattern (as the contour is unrecognizable) with the resultant test score being low.

The duration of the tones, ISI, and IPI may also impact the degree of difficulty of processing and discrimination of FPs. A comparison of these parameters, which are found in the literature, for each FP version can be seen in Table 9. Shorter ISIs require a faster speed of processing, making the task more difficult (Hansen & Hillyard, 1984). This concept can also be applied to shorter IPIs, which would require the auditory system to

recover quickly, thus placing greater demand on the system (Polich, 1990). Tone duration may also impact perceived difficulty. Hartmann, Packard, and Rakerd (1985) demonstrated that as the duration of two tones decreased, the uncertainty in frequency discrimination increased.

Table 9

Tone Duration, ISI, and IPI Comparison for FP Test Versions.

Parameter	Auditec	Aud. Ill.	VA
Tone duration	200 ms.	150 ms.	150 ms.
ISI	150 ms.	200 ms.	200 ms.
IPI	7 s.	7 s.	6 s.

Note. Published parameters from: Auditec, 2014; Musiek & Pinheiro, 1987; Musiek, 1994.

The Auditec and Aud. Ill. versions have a longer IPI (7 s) compared to the VA version (IPI of 6 s) (Auditec, 2014; Musiek, 1994; Musiek & Pinheiro, 1987). In addition, the Auditec version has the longest tone duration (200 ms) compared to Aud. Ill and VA versions, which have a tone duration of 150 ms (Auditec, 2014; Musiek, 1994; Musiek & Pinheiro, 1987). Based on the tone duration, IPI, and greatest difference between high and low tones, the Auditec version can be expected to result in the best patient performance. The Aud. Ill. and VA versions differ solely on IPI, in that the Aud. Ill. version has a longer IPI (7 s) than the VA version (6 s) (Musiek, 1994; Musiek & Pinheiro, 1987). Based on the fact that a shorter IPI places a greater demand on the auditory system, requiring it to recover quickly, the Aud. Ill. version can be expected to result in better performance than the VA version. Overall, based on the stimulus parameters of these three FP test versions, performance can be expected to be the best for the Auditec version, followed by the Aud. Ill. version, followed by the VA version. This expectation was met in the current study. In order to confirm that the difference in performance between the Aud. Ill. version and the VA version was solely the result of the one-second difference in IPIs, two other variables were examined as potential influencing factors on performance. These additional variables included the number of patterns presented to each ear and the acoustic characteristics of the recorded stimuli.

Percent correct scores were recalculated in order to confirm that the significant difference in performance on the Aud. Ill. version compared to the VA version was not due to the number of test items administered. Thirty FPs were administered to each ear for the Aud. Ill. version (Musiek, 1994). In contrast, only 15 patterns were administered to each ear for the VA version rather than the recommended 30 patterns (Musiek, 1994).

The effect of administering fewer items per ear is demonstrated in the following example. If a participant incorrectly repeated four out of thirty patterns on the Aud. Ill version, his score would be 87%. In contrast, four incorrectly repeated patterns out of fifteen on the VA version would result in a score of 73%. The cutoff for receiving failing score on the VA version is 78% and 75% on the Aud. Ill. version (Musiek, 1994; Musiek & Pinheiro, 1987). In the above example, the patient incorrectly repeated the same number of patterns on both versions but received a passing score on the Aud. Ill. version and a failing score on the VA version. As a result of this discrepancy, the Aud. Ill. version was subsequently rescored based on the first 15 patterns presented to each ear. A 2x3 repeated-measures ANOVA was performed a second time to examine the effect of ear (right, left) and FP test version (Auditec, Aud. Ill. [score of first 15 items/ear], and VA) on test score. Post-hoc testing was conducted using the Bonferroni correction for pairwise comparisons for FP test version. The statistically significant difference between the three versions remained.

The Aud. Ill. and VA test versions were subsequently acoustically analyzed, utilizing Audacity software, to compare the acoustic characteristics of the recorded stimuli. The tone duration, ISI, and IPI of the recorded stimuli in the VA version were expected based on the information provided in the literature (Musiek, 1994). In contrast, only the IPI of the stimuli in the Aud. Ill. version was in agreement with the published parameters (Musiek & Pinheiro, 1987). The tone duration was longer (170 ms versus 150 ms) and the ISI was shorter (180 ms versus 200 ms) as compared to the literature (Musiek & Pinheiro, 1987). The longer tone duration and longer IPI for the Aud. Ill. version

compared to the VA version likely allow for easier discrimination of the high versus low tones (Hartmann et al., 1985; Polich, 1990). The published parameters compared to the actual parameters measured in Audacity, can be seen in Table 10.

A spectral analysis of the tones contained in the recording for each version was also completed in the Audacity software. The spectral analysis of one low pitch tone from the VA version and one low pitch tone from the Aud. Ill. version can be seen in Figure 5 and Figure 6, respectively. The energy of the tone for the VA version is centered at one frequency. In contrast, there is significant spectral splatter surrounding the energy of the tone for the Aud. Ill. version. It is concerning that the tone duration and ISI of the Aud. Ill. version do not agree with the published parameters. Additionally, it is concerning that the Aud. Ill. version is not a clean (free of spectral splatter) recording.

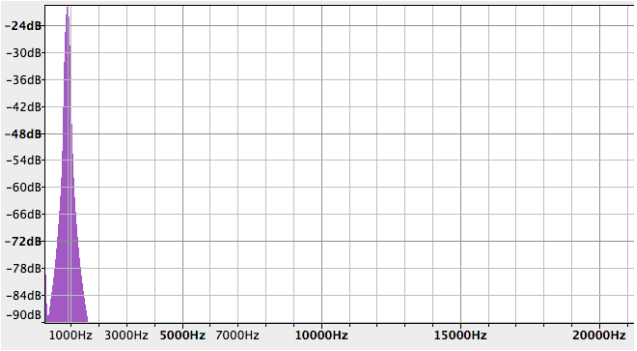

Figure 5. Spectral analysis of a low frequency tone from VA FP version. Screenshot from Audacity software.

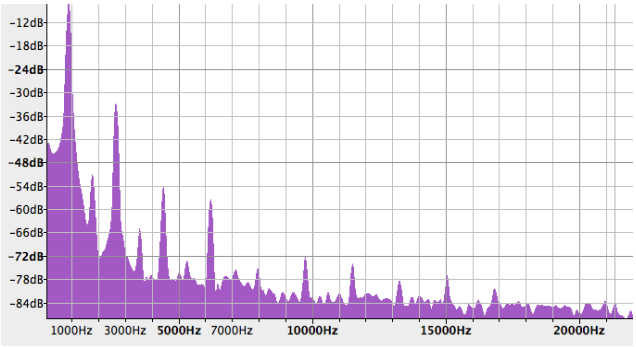

Figure 6. Spectral analysis of a low frequency tone from Aud. Ill. FP version. Screenshot from Audacity software.

Table 10

Published Stimulus Parameters Compared to Actual Measured Parameters for Aud. Ill. and VA FP Test Versions.

Parameter	***Published VA***	**VA**	***Published Aud. Ill.***	**Aud. Ill.**
Tone duration	*150 ms.*	150 ms.	*150 ms*	170 ms.
ISI	*200 ms.*	200 ms.	*200 ms*	180 ms.
IPI	*6 s.*	6 s.	*7 s.*	7 s.

Note. Published parameters from: Auditec, 2014; Musiek & Pinheiro, 1987; Musiek, 1994.

Dichotic digits test versions. The results from this study revealed a statistically significant difference between mean scores on the VA 1-pair digit condition and all other DD versions, and between mean scores on the VA 3-pair digit condition and all other DD versions. There was no significant difference between mean scores on the Auditec version compared to the Aud. Ill. version. Statistical analyses and examination of passing rates suggested performance was similar between the Auditec, Aud. Ill., and VA 2-pair digit condition; performance was the best on the VA 1-pair digit condition; performance was the worst on the VA 3-pair digit condition. There was a significant ear effect for all versions.

The presence of a right ear advantage on tests of dichotic listening has been well established (Kimura 1961, 1964; Milner et al., 1968; Musiek, 1983; Sparks & Geschwind, 1968). In the present study, there was a significant effect of ear on test score for all DD test versions. Mean scores were higher for digits presented to the right ear compared to scores for digits presented to the left ear, which is consistent with previous studies (Kimura 1961, 1964; Milner et al., 1968; Musiek, 1983; Sparks & Geschwind, 1968). The percent differences between the right and left ears for each DD test version can be seen in Table 11. The difference between right and left ears increased as the number of digits increased on the VA test version (2.16% for 1-pair to 6.7% for 3-pair). Wilson and Jaffe (1996) and Strouse and Wilson (1999a, 1999b) found that the right ear advantage increased with increased complexity of the stimulus (the number of digits). In contrast, with less difficulty (e.g. 1-pair digit condition), there was little difference

between ears and a small or no right ear advantage (Kimura, 1961; Strouse & Wilson, 1999a, 1999b). These findings can be attributed to high and low workload on verbal working memory (Moncrieff & Wilson, 2009; Salthouse, Mitchell, Skovronek, & Renee, 1989).

Table 11

Mean Percent Correct Scores for Right and Left Ears on the DD Test Versions and Percent Differences Between Ears.

Ear	Auditec	Aud. Ill	VA 1-pair	VA 2-pair	VA 3-pair
Right	96.43%	95.57%	98.83%	96.83%	90.50%
Left	91.57%	92.87%	96.67%	91.50%	83.80%
Right-left difference	4.86%	2.7%	2.16%	5.33%	6.7%

In the present study, mean scores were highest for the VA 1-pair condition and lowest for the VA 3-pair condition. Several researchers have demonstrated that as the complexity of the DD listening task increased from easy (1-pair digits) to difficult (3-pair digits), there was a corresponding decrease in recognition performance, with a greater decrease in performance noted in older participants (Strouse & Wilson, 1999a, 1999b; Wilson & Jaffe, 1996). Memory and information processing may contribute to this age-complexity relationship (Salthouse et al., 1989; Strouse & Wilson, 1999b).

Working memory is defined as the "preservation of information while simultaneously processing the same or other information" (Salthouse & Babcock, 1991, p.763). Salthouse and Babcock (1991) found that increased age was associated with decreased performance on tasks designed to employ working memory. In addition, they found that efficiency of processing (measured through Arithmetic and Sentence Comprehension tasks) was a key factor contributing to these age related differences in working memory (Salthouse & Babcock, 1991). Age related changes in cognitive functioning can be explained in a processing-resource model (Salthouse et al., 1989). Salthouse et al. (1989) proposed that performance decreases with increased task complexity (e.g. 3-pair digits) because of greater demands on limited processing resources. Likewise, Murdock (1961) found that the probability of recall of verbal items (consonants and words) decreased with longer duration of interrupted activity (counting backwards). This finding is related to the duration of time in which the verbal items had to be maintained in working memory (Murdock, 1961). In addition to a greater number of digits in the VA version, there is also a variable of uncertainty, such that the listener does not know beforehand how many digits will be presented (Moncrieff & Wilson, 2009).

In this situation, the listener must retain all of the digits in working memory until he/she is sure all of the digits were presented before repeating them (Moncrieff & Wilson, 2009).

In contrast, tasks that are less demanding may result in ceiling level performance. Dichotic digit tests that include 1-pair and/or 2-pair digit conditions may result in ceiling effects as a result of familiarity of stimuli and low verbal workload (Moncrieff & Musiek, 2002). Strouse and Wilson (1999b) suggested that 1-pair and 2-pair digit tests have little effective clinical utility because the tests are too easy. Musiek (1983) found that normal hearing and hearing impaired participants performed near ceiling on the 2-pair DD test. Recognition performance of 1-pair digits was near 100% and within normal limits for all ages (up to age 79 years) (Strouse & Wilson, 1999a; Wilson & Jaffe, 1996). In the present study, performance was near ceiling for recognition of 1-pair digits.

Clinical Implications

The main purpose of APD testing is to differentiate between normal and abnormal performance. Interpretation of performance on tests of APD is based on normative cutoff scores. Cutoff scores are set at levels to achieve the best balance between sensitivity and specificity (AAA, 2010). A diagnosis of APD is guided by the following criteria: a score two standard deviations or more below the mean for a least one ear on at least two different tests (AAA, 2010). The variations in difficulty of different APD tests and test versions are reflected in the normative data.

Normative data for frequency pattern test versions. The cutoff scores for the FP versions, indicating abnormal performance were 88% for the Auditec version (Auditec, 2014); 78% for the VA version (Musiek, 1994); 75% for the Aud. Ill. version

(Musiek & Pinheiro, 1987). These cutoff scores indicate that performance would be best for the Auditec version, followed by the VA version, and worst for the Aud. Ill. version. In the current study, performance was best for the Auditec version; however, performance was worse on the VA version compared to the Aud. Ill. version, which is not in agreement with the normative data.

Normative data for the tests included on the VA CD was obtained in a series of studies referred to as the "compact disc trials" (Noffsinger et al., 1994). The tests (including the VA FP version) were administered to 120 young adults (M=23 years of age) with normal hearing sensitivity (Noffsinger et al., 1994). Musiek (1994) administered the VA FP test to this group of subjects and found that 90% of the scores were 78% or better. He suggested that this value should be used to define normal performance (Musiek, 1994).

Musiek developed the Aud. Ill. FP test version (Musiek & Pinheiro, 1987). Musiek and Geurkink (1982) found that a score of 75%, used to define abnormal performance, resulted in a false positive rate of only 4.7% in normal hearing adults. Musiek and Pinheiro (1987) evaluated participants with cerebral, brainstem, and cochlear lesions. Utilizing the 75% cutoff score, they found that the FP test had good sensitivity and specificity in identifying those with cerebral versus cochlear lesions (Musiek & Pinheiro, 1987). The administration instructions that accompany the Aud. Ill. CD suggest utilizing a cutoff score of 75% to define abnormal performance in individuals ages 11 years and older (Musiek & Pinheiro, 1987).

The Auditec FP test version is a recording produced by Pinheiro (K. Bond, personal communication, April 16, 2014). The normative data for this test was provided

to Auditec by Pinheiro (K. Bond, personal communication, April 16, 2015). The administration instructions that accompany the Auditec CD include means and ranges with no references (Auditec, 2014). The instructions that are provided suggest utilizing a cutoff score of 88% to define abnormal performance (Auditec, 2014). It is unclear as to how this cutoff score was derived. Several sources suggest that Pinheiro is responsible for producing the Auditec FP version and refer the consumer to her preliminary studies (Auditec, 2014; Chermak, 1996; K. Bond, personal communication, April 16, 2014; Mukari et al., 2010). This is confusing as the Auditec FP version utilizes high and low tones of 1430 Hz and 880 Hz, and Pinheiro's preliminary studies utilize high and low tones of 1120 and 880 Hz (Pinheiro, 1977; Musiek & Pinheiro, 1987).

Normative data for dichotic digits test versions. The cutoff scores for the DD versions, indicating abnormal performance are 90% for the Auditec version (Auditec, 2014); 90% for the Aud.Ill. version (Musiek, 1983); varied depending on age and number of digits for the VA version (Strouse & Wilson, 1999a). The cutoff scores for the DD versions indicate: (a) performance will be best for the VA 1-pair condition; (b) performance will be equal for the VA 2-pair digit condition, Aud. Ill. version, and Auditec version; and c) performance will be the worst for the VA 3-pair digit condition. The findings of the current study reflect the variations in difficulty as indicated by the normative data.

Normative data for the VA DD test version was determined by Strouse and Wilson (1999a, 1999b). The test was administered to 180 subjects, ages 20 to 79 years of age. Each digit condition (1-, 2-, and 3-pair) was scored separately and participants were separated into groups based on their age. The 95% confidence interval of scores for age

groups pertinent to the current study can be seen in Table 8. Normative data for the VA version indicate that the task becomes more difficult with an increase in age and with an increase in the number of digits (Strouse & Wilson, 1999a, 1999b).

The Aud. Ill. DD version was created by Musiek (1983). The administration instructions that accompany this CD suggest utilizing a cutoff score of 90% (2 SD) to define abnormal performance in individuals ages 12 years and older (Musiek, 1983; Musiek et al., 1991). The administration instructions that accompany the Auditec DD version suggest utilizing a cutoff score of 90% (2 SD) for individuals ages 12 years and older (Auditec, 2014). The clinician is referred to a book published by Bellis in 2003 (Auditec, 2014). The normative data provided in Bellis (2003, p. 243), is identical to the normative data provided by Musiek (Musiek, 1983; Musiek et al., 1991).

Recommendations for clinical use. Based on the findings of this study, and in consideration of normative cutoff scores, the VA FP test version and Auditec or Aud. Ill. DD test versions are recommended for clinical use.

The VA FP test version is recommended for clinical use rather than the Auditec version because Auditec cutoff scores (88%) suggest near-ceiling performance. In addition, reversals are scored as correct on the Auditec versions (Auditec, 2014). It has been suggested that reversals be scored as incorrect because some patients with central pathology have many reversals, and will not be identified if reversals are considered to be correct (Musiek et al., 1980). The Aud. Ill. version is not recommended for clinical use because the acoustic analysis of the stimulus recording was not in agreement with the published test parameters, specifically the tone duration and ISI. In addition, the Aud. Ill. version was not a clean recording, with significant spectral splatter noted for the tones.

The Auditec or the Aud. Ill. DD test version is recommended for clinical use. Performance was not significantly different between the Auditec and Aud. Ill. DD test versions, which was in agreement with normative cutoff scores. Strouse and Wilson (1999b) suggested that the VA version could be used to evaluate a wider range of recognition performance, which may be useful in differentiating the perceptual abilities of different individuals. Moncrieff and Wilson (2009) administered the VA DD test version to children and young adults between the ages of 10 to 28 years and concluded that it is a "useful clinical instrument for evaluating dichotic listening performance in children" (p. 69). Despite these suggestions, the VA version was not recommended for general clinical use for several reasons.

First, the VA version places more demands on cognitive processes such as memory, which adds in other variables that need to be considered (Murdock, 1961; Salthouse et al., 1989). Second, the VA version requires a longer period of sustained attention and focus in order to correctly recall all of the digits, specifically for the 3-pair digit condition (Moncrieff & Wilson, 2009; Murray & Hitchcock, 1969; Strouse & Wilson, 1999b). Third, each digit condition (1-, 2-, 3-pair digits) is scored separately and then compared to normative data for each digit condition for each ear for the age of the individual (Strouse & Wilson, 1999a, 1999b). This method of scoring is time consuming and can be confusing, which may lead to scoring errors; therefore, this test version may not be practical in the typical audiologic setting. Additionally, this test version may be difficult to compare to other tests of dichotic listening (e.g. competing words) as a result of the scoring method. Rather than the ability to simply compare right and left ears on the

DD test to other tests of dichotic listening, the VA version has six conditions to consider: 1- pair right ear, 1- pair left ear, 2- pair right ear, 2- pair left ear, 3- pair right ear, and 3- pair left ear.

Study Limitations and Future Research

In reviewing the findings of this study, it is important that the limitations of the study are taken into account. In addition, continued research in the assessment and diagnoses of APD has long been suggested; this suggestion remains based on the current study.

Sample size. This study consisted of 30 participants between the ages of 55 to 73 years (M= 62.03 years). Seventy percent of participants were female and only 30% were male. All of the participants had at least a high school education. With a relatively small sample size of similar participants (educated, mostly female, older adults), the findings cannot be generalized to assessment of the general population. Future research should include a more diverse sample, especially with the inclusion of children.

Test administration. Most of the CDs used for test administration were from the companies who distribute the CDs, with the exception of the VA CD (VA FP and VA DD versions), which was a burned copy of the actual CD that is provided by the VA. It is unknown if the use of a copied CD had an effect on the results of this study. Another limitation of test administration in this study was the presentation of only 15 items per ear, rather than the recommended 30 items per ear, on the VA FP version (Musiek, 1994). This was corrected for by re-scoring the Aud. Ill. FP version based on the first 15 items presented to each ear; however, it cannot be ascertained that administering 15 patterns per ear on the VA version did not adversely affect the findings of this study. This study only

evaluated differences between three of the available FP versions and three of the available DD versions; future research should evaluate the various versions of other tests of auditory processing (e.g. monaural low redundancy).

Conclusions

Despite the publication of guidelines and consensus reports, controversy and confusion remain regarding the assessment, diagnosis, and rehabilitation of APD. The numerous tests and test versions for use in APD assessment, is likely one reason for this confusion. The purpose of this study was to determine if three different versions of the DD test and three different versions of the FP test, resulted in the same or different performance in older adults, in order to help lessen the ambiguity of APD assessment. Statistically significant differences were found between the mean percent correct scores between the DD test versions and FP test versions. Additionally, the percentage of individuals who received a passing score varied across test versions, especially for the FP test versions. Of the participants who failed at least one test version in at least one ear, any other tests that they failed varied across the test versions, especially for the DD test versions. This variability in failed tests across participants and the variability in passing rates across test versions is clinically significant and highlights the need for continued research in the assessment process of APD.

Differences in performance were found across all of the test versions included in this study. In general, as the complexity of the stimuli and difficulty of the task increased, performance decreased. The VA FP test version and Auditec or Aud. Ill. DD test versions are recommended for clinical use. The awareness of significant differences in performance on different test versions of the same test type of auditory processing ability

is clinically significant. The lack of a universal standardized method of assessment and the lack of normative data that is consistently two SD from the mean is potentially detrimental to the proper identification of APD and implementation of appropriate intervention strategies. A standardized method of assessment is imperative for the outcome of individuals suspected of having a diagnosis of APD. For example, an audiologist using the Aud. Ill. FP test version may not find evidence of APD in a patient and a different audiologist using the VA FP test version may find evidence of APD in that same patient. This discrepancy may result in patients falling through the cracks, which has implications for deficits in listening, communication, academic achievement, job performance, and social skills (AAA, 2010).

Appendices

Appendix A: Institutional Review Board Approval

TOWSON UNIVERSITY

RENEWED APPROVAL NUMBER: 11-A050R2

To: Stephanie Nagle

From: Institutional Review Board for the Protection of Human Subjects, Gerald Jerome, Member

Date: Wednesday, January 12, 2011

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

Office of Sponsored Programs & Research

Towson University
8000 York Road
Towson, MD 21252-0001

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

Thank you for completing the Annual Review Notice for Projects Involving Human Participants for the project titled:

Central Auditory Processing - Assessment and Rehabilitation

Since you have indicated that your research project is still active, we are granting you a renewal of your approval. If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should there be substantive changes in your research protocol, you will need to submit another application for approval at that time. This protocol will be reviewed again one year from this date of approval.

We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC:
File

Institutional Review Board for the Protection of Human Participants
Towson University
Annual Review Notice for Projects Involving Human Participants

Principal Investigator: **Stephanie Nagle**

Title of Project: Central Auditory Processing - Assessment and Rehabilitation

Date of Approval: 1/12/2011 **Approval Number:** 11-A050R1

Principal Investigator Department/Affiliation: AUDS

PRINCIPAL INVESTIGATORS ARE REMINDED THAT THEY ARE REQUIRED TO ASSURE THE CONFIDENTIALITY OF ALL DATA AND THAT ANY BREACH OF CONFIDENTIALITY MUST BE REPORTED TO THE IRB.

1. PROJECT STATUS (Please check all items which apply.)

a.INACTIVE
(1)No further contact with human participants or record required:
_____Original data and/or research materials have been destroyed.
_____The linkages between existing data and original source of information have been destroyed. No individuals can be identified from existing data.
_____The data with identifiers will be retained. (Indicate in a separate memorandum why such data will be retained, where and how long and attach.)
ANNUAL REPORT REQUIRED.

b.ACTIVE
(2) ___✓___Contact with human participants is still required.
(Will field interviews still be required this year? _____Yes _____No)
___✓___Data are still being collected from records or other sources.
___✓___Data are still being analyzed.
___✓___Original procedures for protecting human participants are still in effect. (If There have been changes, please describe in a separate memorandum.)

2. Has there been any evidence either from your experience to date or from recent literature which indicate the existence of risks different from those previously described?
____Yes ___✓___No (If yes, describe briefly in a separate memorandum and attach.)
3. What is the number of participants accrued this year? _____, since the study began? ____
4. Has the study been active for three years? ___✓___Yes _____No
(If yes, attach a separate document summarizing the research thus far.)
5. Has there been any withdrawal of participants from the research? _____Yes ___✓___No
Have there been any complaints about the research? _____Yes ___✓___No (If yes, briefly describe in a separate memorandum and attach.)
6. If applicable, you MUST submit a copy of the most current informed consent document..

Signature: Stephanie Nagle

Faculty Sponsor Principal Investigator

DO NOT WRITE BELOW THIS LINE -- IRB USE ONLY

___✓___Protocol is as previously approved; research may continue.
_____Protocol is as previously approved but risks have increased based on current knowledge, IRB review necessary.
_____Project is complete; IRB records closed; and linkages have been destroyed.
_____Project is complete; IRB records closed; records will be retained and investigator will continue to assure confidentiality and to advise IRB of any breech of confidentiality.

Signature: _____ Date 1/30/15

Towson University IRB Chairperson

Appendix B: Consent Form for Participation in Research Project

Consent Form for Participation in a Research Project

Principal Investigator: Stephanie Nagle
Study Title: Central Auditory Assessment & Rehabilitation

1. Invitation to Participate
   You are invited to participate in a study of hearing by Dr. Stephanie Nagle of Towson University. Please read this form and ask any questions you may have before agreeing to be in the research study.

2. Purpose
   The purpose of this study is to help determine which tests among several are the best to diagnose certain types of hearing disorders.

3. Description of Procedures
   If you participate in this study, you will be required to listen to a variety of sounds such as tones, parts or words, words, and noises. You will be asked to tell us what you/he/she hears or press a button in response to what you hear. They study will include both normal hearing and hearing impaired individuals. We need to testy our hearing to understand whether the tests we perform during the study are valuable in diagnosing hearing problems. You may be excluded from the study if we find an ear infection or other types of conditions that may interfere with the tests. In some cases, small surface electrodes may be attached to your head or ear lobes with paste to record some response to these various sounds. The electrodes are placed on top of the skin or scalp and do not hurt and the paste is easily removed. For these kinds of tests you will only have to sit quietly. The testing procedure may take from approximately one to two hours. Breaks from testing will be provided on a regular basis, and as requested. The experiments will take place at Towson University. An average experiment will take about 1.5 hours.

   You may be asked to fill out a questionnaire or case history related to hearing and communication difficulties. Your spouse or other communication partner may also be asked to fill out an auditory questionnaire about his/her perception of your hearing history and behavior.

4. Risks and Inconveniences

- We believe there are no risks to you for your participation. No discomfort is associated with the task other than the usual fatigue or boredom related to sitting for an hour or two. The electrode cream used for some studies is non-toxic and washes off the skin easily, but if the electrodes are placed on the head, removal of all cream may require the use of shampoo at home.

5. Benefits

You may benefit directly from clinical assessment of your hearing, and central auditory processing abilities, and by therapeutic recommendations made based on those assessments. We hope this study may help to develop reliable tests and treatments which better diagnose and treat hearing disorders in the population as a whole.

6. Economic Considerations

You will not be paid nor will you be charged for participation in the study.

7. Confidentiality

The records from his study will be kept private. In any report published or presented regarding this study there will be no information that reveal your identity. Records will be kept in a locked room and only researchers will have access to these records.

8. Voluntary Participation

You do not have to be in this study if you do not want to. If you agree to be in the study, but later change your mind, you may drop out at any time. There are no penalties or consequences of any kind if you decide that you does not want to participate. Your decision as to whether or not to participate will in no way affect any treatment at the Speech and Hearing Clinic or your student status at Towson University.

9. Do You Have Any Questions?

Take as long as you like before you make a decision. We will be happy to answer any question you or your child have about this study. If you have further questions about this project or if you child have a research-related problem, you may contact the principal investigator, Dr. Stephanie Nagle, at (410) 704-3920. If you have any questions concerning your rights as a research participant, you may contact Dr. Debi Gartland, Chairperson, Towson University Institutional Review Board (IRB), at 410-704-2236.

Authorization:

I have read this form and decided that I, _____ will
(name of subject)
participate in the project described above. Its general purposes, the particulars of involvement and possible hazards and inconveniences have been explained to my satisfaction.

Signature:_____

Date: _____

_____ _____
Signature of Primary Investigator Phone

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY.

Appendix C: Saint Louis University Mental Status exam

VAMC
SLUMS Examination

Questions about this assessment tool? E-mail aging@slu.edu.

Name_____ Age _____

Is patient alert? _____ Level of education _____

__/1 (1) **1. What day of the week is it?**

__/1 (1) **2. What is the year?**

__/1 (1) **3. What state are we in?**

4. Please remember these five objects. I will ask you what they are later.

Apple Pen Tie House Car

5. You have $100 and you go to the store and buy a dozen apples for $3 and a tricycle for $20.

(1) **How much did you spend?**

__/3 (2) **How much do you have left?**

6. Please name as many animals as you can in one minute.

__/3 (0) 0-4 animals (1) 5-9 animals (2) 10-14 animals (3) 15+ animals

__/5 **7. What were the five objects I asked you to remember?** 1 point for each one correct.

8. I am going to give you a series of numbers and I would like you to give them to me backwards. For example, if I say 42, you would say 24.

__/2 (0) 87 (1) 649 (1) 8537

9. This is a clock face. Please put in the hour markers and the time at ten minutes to eleven o'clock.

(2) Hour markers okay

__/4 (2) Time correct

__/2 (1) **10. Please place an X in the triangle.**

(1) **Which of the above figures is largest?**

11. I am going to tell you a story. Please listen carefully because afterwards, I'm going to ask you some questions about it.

Jill was a very successful stockbroker. She made a lot of money on the stock market. She then met Jack, a devastatingly handsome man. She married him and had three children. They lived in Chicago. She then stopped work and stayed at home to bring up her children. When they were teenagers, she went back to work. She and Jack lived happily ever after.

__/8 (2) **What was the female's name?** (2) **What work did she do?**

(2) **When did she go back to work?** (2) **What state did she live in?**

_____ **TOTAL SCORE**

Department of Veterans Affairs

SAINT LOUIS UNIVERSITY

Scoring		
High School Education		Less than High School Education
27-30	Normal	25-30
21-26	MNCD*	20-24
1-20	Dementia	1-19

* Mild Neurocognitive Disorder

SH Tariq, N Tumosa, JT Chibnall, HM Perry III, and JE Morley. The Saint Louis University Mental Status (SLUMS) Examination for Detecting Mild Cognitive Impairment and Dementia is more sensitive than the Mini-Mental Status Examination (MMSE) - A pilot study. J am Geriatri Psych (in press).

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