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THE EFFECT OF VARYING TEST ADMINISTRATION AND SCORING PROCEDURES ON THE TEST RELIABILITY OF THREE TESTS OF AUDITORY PROCESSING DISORDER

by

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THESIS APPROVAL PAGE

This is to certify that the thesis prepared by Maria E. Pomponio, B.A., Au.D. Candidate, entitled The Effect of Varying Test Administration and Scoring Procedures on the Test Reliability of Three Tests of Auditory Processing Disorder has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree Doctor of Audiology (Au.D.).

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ii

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ABSTRACT

THE EFFECT OF VARYING TEST ADMINISTRATION AND SCORING PROCEDURES ON THE TEST RELIABILITY OF THREE TESTS OF AUDITORY PROCESSING DISORDER

Maria E. Pomponio

The auditory processing abilities of 33 older adults (10 male, 23 female) ranging in age from 50 to 65 years were evaluated using the Frequency Pattern Test (FPT), Competing Sentences Test (CST), and Low-Pass Filtered Speech Test (LPFST). All participants were given each test: (1) in accordance with published guidelines relative to number of test items, use of repetitions of incorrectly answered test items, and scoring methods used to standardize the test; and (2) with variances from standardized methodology specific to number of test items, use of repetitions, and scoring methods. Results revealed significant effects of varying use of repetitions, as well as an interaction between number of test items and use of repetitions, on test outcome. Based on these findings, it is imperative that audiologists administer tests of auditory processing disorder (APD) in accordance with published guidelines in order to improve test reliability. If audiologists choose to vary test administration procedures from those used to standardize the test, they must obtain their own normative data values by which to compare their results. In doing so, over-diagnosis of APD will be reduced and the diagnostic value of tests of APD will be enhanced. It is this author's hope that by highlighting the importance of maintaining uniform test administration and scoring procedures, at least a portion of the current controversy surrounding the assessment and diagnosis of APD will be reduced.

TABLE OF CONTENTS

LIST OF FIGURES

Page

KEY TO ABBREVIATIONS

AAA: American Academy of Audiology

ABR: Auditory Brainstem Response

ANOVA: Analysis of Variance

AP: Auditory Processing

APD: Auditory Processing Disorder

ASHA: American Speech-Language-Hearing Association

CANS: Central Auditory Nervous System

CAPD: Central Auditory Processing Disorder

(C)APD: (Central) Auditory Processing Disorder

CD: Compact Disc

CID-W22: Central Institute for the Deaf—Word List 22

CNS: Central Nervous System

CST: Competing Sentences Test

daPa: Dekapascal

dB: Decibel

dB HL: Decibel Hearing Level

dB SL: Decibel Sensation Level

ER-3A: Etymotic Research 3A

FPT: Frequency Pattern Test

GSI-61: Grason Stadler Instrument—61

Hz: Hertz

IRB: Institutional Review Board

LPFST: Low-Pass Filtered Speech Test

MANOVA: Multivariate Analysis of Variance

ml: Milliliter

MMSE: Mini-Mental State Examination

MRI: Magnetic Resonance Imaging

msec: Millisecond

NU-6: Northwestern University Auditory Test No. 6

PB-50: Phonetically Balanced 50-word List

PTA: Pure Tone Average

REA: Right Ear Advantage

SD: Standard Deviation

SSI: Synthetic Sentence Identification

Chapter 1

Introduction

Auditory Processing Disorder (APD) is a term used to describe listening difficulties that result from the inability of an individual's central auditory nervous system (CANS) to appropriately integrate auditory input (ASHA, 2005). Specifically, APD can manifest in a number of ways, including: (a) difficulty understanding speech in the presence of background noise, (b) needing frequent repetitions, and (c) difficulty following verbal directions; however, the presenting symptoms are often not specific to APD (i.e., they can be, and often are, reported by individuals experiencing a variety of other disorders) and vary from case to case (ASHA, 2005). Additionally, APD can occur as a standalone diagnosis or in conjunction with another disorder (ASHA, 2005).

A number of consensus statements have agreed that APD should be diagnosed by a licensed audiologist after a patient displays poor performance on at least two tests within the auditory processing (AP) test battery (AAA, 2010; ASHA, 2005). At present, there is controversy surrounding the use of behavioral tests of AP ability to diagnose APD. Specifically, researchers have cited insufficient academic and clinical preparation on the graduate level, as well as the lack of a "gold standard" to objectively measure APD, as reasons that APD should not be considered a true clinical disorder (Bellis, 2006; Chermak, Traynham, Seikel, & Musiek, 1998; Chermak, Traynham, Seikel, & Musiek, 2007; Emanuel, 2002; Sykes, Tucker, & Herr, 1997). Additionally, when audiologists administer the same tests of AP ability in different ways, the reliability and overall diagnostic significance of the test is diminished (Bellis, 2003). This variability enhances skeptics' opinions that APD is not a true clinical disorder (Bellis, 2006; Emanuel, 2002).

In order to strengthen the diagnostic significance of behavioral tests of AP ability, clinicians must be aware of patient, procedural, and tester variables that can affect the outcome of the test, and are obligated to control for them as much as possible (Bellis, 2003). By holding these variables constant between patients and across clinicians, it is possible to increase the reliability of tests of APD. In doing so, the likelihood of misdiagnosing APD will significantly decrease and the validity of the tests will increase (DeBonis & Moncrieff, 2008; Young, 1985).

The goal of this study is to determine if varying tester variables inherent to AP tests, specifically: (a) the number of test items administered, (b) repeating test items initially answered incorrectly, and (c) method of scoring, affects the outcome of the test and thus the overall diagnosis of APD. It is this author's hope that the present study will serve as a reminder to all practicing audiologists that test administration procedures play a crucial role in the validity, and thereby diagnostic significance, of the test's outcome. In an effort to maintain the credibility of AP assessment, clinicians must agree to administer these tests using uniform, consistent procedures. If they choose to modify test administration from standardized procedures, audiologists must acknowledge the need to obtain site- and procedure-specific normative data by which to compare their results so as to not sacrifice the validity of the test. Doing so will significantly weaken the arguments of those who oppose the legitimacy of APD diagnoses due to the lack of a "gold standard" diagnostic criterion.

Chapter 2

Review of the Literature

History

Auditory Processing Disorder (APD), sometimes referred to as Central Auditory Processing Disorder (CAPD) or (Central) Auditory Processing Disorder [(C)APD], has been an evolving and controversial specialty area in the field of audiology since the 1950s, when its importance was first recognized in the literature and the first reports of clinical assessment of central auditory dysfunction appeared (AAA, 2010; ASHA, 2005; Bocca, Calearo, Cassinari, & Migliavacca, 1955; Emanuel, 2002; Emanuel, Smart, Bernhard, & McDermott, 2013; Whitelaw, 2008). A number of consensus statements have been issued over the last several decades in attempts to refine the definition and understanding of APD (e.g., AAA, 2010; ASHA, 2005; Jerger & Musiek, 2000); however, there still appears to be a lack of agreement regarding the definition, assessment, diagnosis, and intervention of APD (Cacace & McFarland, 1998; DeBonis & Moncrieff, 2008; Dillon, Cameron, Glyde, Wilson, & Tomlin, 2012; Emanuel et al., 2013; Whitelaw, 2008).

Definition and Differential Diagnosis

The American Academy of Audiology (AAA) defines APD as an impaired ability of the CANS to appropriately process auditory input (AAA, 2010). According to the American Speech-Language-Hearing Association (ASHA), this dysfunction is evidenced by poor performance in one or more of the following areas: (a) correct localization and lateralization to sound; (b) auditory discrimination and pattern recognition; (c) temporal integration, discrimination, patterning, and masking; and (d) auditory function in the

presence of competing or degraded acoustic stimuli (ASHA, 2005). APD is a true clinical disorder that can occur in children, adults, and the elderly (AAA, 2010; ASHA, 2005; DeBonis & Moncrieff, 2008). The current prevalence of APD is estimated at 2-3% of the total pediatric population (O'Beirne, McFaffin, & Rickard, 2012), and anywhere from 17% to as great as 95% of older adults (≥80 years old) (Stach, Spretnjak, & Jerger, 1990).

Often times, APD is the result of diffuse dysfunction of the central nervous system (CNS) with no identifiable lesion (AAA, 2010). APD can occur independently or coexist with other disorders and/or learning problems (e.g., speech and language disorder, reading disability/dyslexia, attention deficit disorder) (ASHA, 2005; Cacace & McFarland, 1998; Dawes, Bishop, Sirimanna, & Bamiou, 2008; DeBonis & Moncrieff, 2008; Jerger & Musiek, 2000).

Presenting Symptomology

Due to the non-modular nature of the CNS, APD is primarily, but not exclusively, specific to the auditory system (AAA, 2010; ASHA, 2005; DeBonis & Moncrieff, 2008; Musiek, Bellis, & Chermak, 2005). In fact, symptoms of APD vary from case to case and are often not unique to this disorder. Rather, these symptoms could easily be seen accompanying alternative disorders such as attention deficit disorder and speech and language impairment (Emanuel et al., 2011). This has driven skeptics to argue against the legitimacy of APD as a standalone diagnosis (AAA, 2010; DeBonis & Moncrieff, 2008; Jerger & Musiek, 2000; O'Beirne et al., 2012).

According to ASHA (2005), individuals with similar auditory processing deficits may display different functional impairments based on unique neurobiological, social, and environmental factors. Symptoms often observed in individuals with APD include:

(a) need for frequent repetitions; (b) saying "huh" or "what" repeatedly; (c) limited auditory attention and difficulty attending to auditory stimuli; (d) difficulty understanding speech in noisy or adverse listening environments; (e) difficulty localizing a sound source; (f) difficulty understanding degraded speech; (g) difficulty following verbal directions; (h) delayed oral responses to questions; (i) difficulty detecting humor and sarcasm in speech; (j) distractibility; and (k) reading, learning, spelling, or language problems (AAA, 2010; ASHA, 2005; DeBonis & Moncrieff, 2008; Dillon et al., 2012; Smoski, Brunt, & Tannahill, 1992; Young, 1985). Additionally, children with APD are often described as poorer listeners than their same-age classmates (Smoski et al., 1992).

Test Battery Approach

There is consensus in the literature that a test battery approach should be used for the assessment of APD (e.g., AAA, 2010; ASHA, 2005; Bellis, 2003; Bellis, 2006; Cacace & McFarland, 1998; DeBonis & Moncrieff, 2008; Musiek, Chermak, Weihing, Zappulla, & Nagle, 2011; O'Beirne et al., 2012). Test batteries measure the function of several complex levels within the CANS responsible for AP during a single evaluation (AAA, 2010; Emanuel et al., 2011). This is particularly important for the assessment of APD because, as mentioned, the organization of the CNS allows multiple areas of the system to influence an individual's ability to process auditory input. Additionally supporting the concept of a test battery approach is the cross-check principle, which was first introduced by Jerger and Hayes in 1976. The concept behind the cross-check principle and more broadly, a test battery approach, is the use of multiple tests within an assessment to increase the validity of the diagnostic outcome (Jerger & Hayes, 1976).

Test batteries should contain both behavioral and electrophysiological tests with known sensitivity, specificity, and efficiency in their ability to measure the functionality of various levels of the CNS (AAA, 2010; ASHA, 2005; Bellis, 2006; Jerger & Musiek, 2000; Musiek et al., 2011; Musiek et al., 2005; Musiek & Chermak, 1994). The sensitivity of a test refers to its ability to correctly identify APD in individuals with the disorder, or its true positive outcomes, whereas the specificity of a test refers to its ability to correctly reject the presence of APD in individuals without the disorder, or its true negative outcomes (ASHA, 2005; Bellis, 2003; Bellis, 2006; Musiek et al., 2011). A test's efficiency is the percentage of the total test outcomes that are correct, or the test's ability to correctly identify or reject the presence of a disorder in individuals who have or do not have the disorder, respectively (Bellis, 2003; Musiek et al., 2011). Test batteries comprised of individual measures that are high in sensitivity, specificity, and efficiency will have higher diagnostic values (i.e., yield more accurate diagnoses) and are therefore more "desirable" than batteries comprised of measures that are not sensitive, specific, or efficient (Musiek et al., 2011, p. 356; AAA, 2010). Tests of APD should also have consistent test-retest reliability (Musiek et al., 2011; Musiek & Chermak, 1994). Because different tests are more appropriate for assessing different areas of CNS function, and because each patient presents with varying symptoms and functional deficits, test batteries should be individualized for each patient (Musiek & Chermak, 1994).

Test Administration Considerations

The AP test battery should be administered by a licensed audiologist who is trained in the administration and interpretation of tests of APD (AAA, 2010). This is in accordance with ASHA's Code of Ethics, which states, "individuals may practice only in

areas in which they are competent based on their education, training, and experience" (ASHA, 2005, p. 2). Ideally, the test battery should be completed within a 45-60 minute time frame. After 60 minutes, it is possible that patient fatigue, inattention, and/or lack of motivation will set in and adversely affect the test results (AAA, 2010).

Age and APD. As a result of increased age, older individuals experience a decline in peripheral auditory and CANS function, which negatively affects the individual's ability to process auditory information (Stach, Loiselle, & Jerger, 1991; Tun, Williams, Small, & Hafter, 2012). Furthermore, there is a reduced degree of CANS neural synchrony and coding abilities in older individuals, which is additionally detrimental to a person's ability to process auditory stimuli (Martin & Jerger, 2005; Tun et al., 2012).

In a 1990 study evaluating the link between aging and APD, Stach, Spretnjak, and Jerger retrospectively analyzed audiometric data from over 700 patients from an audiology clinic at a hospital in Houston, Texas. Subjects were divided into one of seven groups based on years of age (50-54; 55-59; 60-64; 65-59; 70-74; 75-80; 80+). Subjects were defined as having APD based on results of the Synthetic Sentence Identification (SSI) test and phonetically-balanced (PB) 50-word lists. Although seemingly limited in terms of diagnostic tests, the authors chose this test battery in particular due to its ability to control for any possible effects of presbycusis. The SSI, in particular, is essentially resistant to the effects of peripheral hearing loss. Furthermore, normative data by degree of hearing loss exist for both the SSI and PB word tests. The authors found a linear relationship between APD and age such that the prevalence of APD increased with

increasing age. Specifically, the authors found that 17% of their subjects aged 50-54 years displayed APD, rising to 95% of their subjects aged 80 years and older.

Several researchers have expressed concern regarding the assessment of APD in older individuals due to age-related factors that could impact the diagnosis of a true APD. Most notably, researchers argue that the presence of age-related hearing loss (presbycusis) and cognitive decline may potentially confound the results of AP evaluations and hinder the audiologist's ability to obtain a true measure of AP abilities (Cox, McCoy, Tun, & Wingfield, 2008; Humes, 2005; Martin & Jerger, 2005; Stach et al., 1991; Tun et al., 2012). It is necessary when evaluating the AP abilities of adults to separate out deficits due to processing dysfunction and those resulting from increased age (e.g., decreased cognition and peripheral hearing loss) by proactively choosing tests that are somewhat resistant to the effects of peripheral hearing loss, and by screening for decreased or impaired cognition (AAA, 2010; Cox et al., 2008; Howarth & Shone, 2006; Stach, Spretnjak, & Jerger, 1990).

Assessment of APD

Assessment of APD begins with a thorough case history obtained by interviewing the patient, the patient's family members, and/or any other individual(s) capable of providing information specific to the patient's auditory problems and associated difficulties. A detailed case history can assist the audiologist in predicting potential areas of weakness that will be revealed through formal testing. This helps guide the selection of tests to use in the assessment battery (AAA, 2010; ASHA, 2005). If possible, direct observation of the individual at home or in another naturalistic setting (e.g., at school or work) allows the audiologist to observe any functional deficit(s) experienced by the

patient. This information will be useful after the evaluation, as it will assist the audiologist in making appropriate treatment recommendations and setting up necessary rehabilitation programs for the patient (AAA, 2010).

Following the collection of a complete case history, it is recommended that behavioral tests of APD assess the areas of temporal processing, dichotic listening, and monaural low-redundancy speech perception (AAA, 2010; ASHA, 2005). In a 2002 study, Emanuel examined the common practices of 58 licensed audiologists as they relate to administering AP test batteries. Results of the study revealed that 100% of the audiologists surveyed administered a dichotic speech test, 96% administered a monaural low-redundancy speech test, and >60% administered a temporal processing test (61% of mailed respondents and 76% of online respondents, specifically) (Emanuel, 2002). Only a small percentage of audiologists surveyed (<15%) reported that they routinely used electrophysiologic tests as part of their AP test battery (Emanuel, 2002).

Emanuel, Ficca, and Korczak (2011) administered a follow-up survey to evaluate the clinical practices of a larger group of audiologists as they relate to AP evaluations. Responses were obtained from 195 audiologists who self-reportedly specialized in the assessment and diagnosis of APD. An overwhelming majority (97%) of respondents revealed using a test battery to assess APD, 80% of whom reported the use of a minimal test battery that is modified for administration on an individual basis. Results of the completed surveys corroborated earlier conclusions made by Emanuel (2002), in that the most commonly assessed areas of APD are temporal processing, dichotic listening, and monaural low-redundancy speech perception. Also similar to the Emanuel (2002) survey,

results obtained from the Emanuel, Ficca, and Korczak (2011) survey revealed that electrophysiologic tests are rarely included in AP test batteries.

It is important that audiologists administering tests of APD understand the main areas these test batteries assess, particularly the commonly-assessed areas of temporal processing, dichotic listening, and monaural low-redundancy speech perception. As important is the audiologist's ability to select the most appropriate test(s) from these categories to administer on a case-by-case basis.

Temporal processing tests. Temporal processing refers to the ability to process the timing aspects of an auditory signal (Bellis, 2003). Functionally, this relates to a listener's ability to discriminate the subtle cues (nuances) in speech that are necessary for accurate speech and music perception (Shinn, Chermak, & Musiek, 2009). An individual's temporal processing skills can be assessed through the use of either temporal patterning or temporal resolution tests. Temporal patterning tasks require the listener to identify non-speech patterns (often tones or clicks) and repeat them in the correct sequence (Bellis, 2003). Temporal resolution tests assess an individual's ability to identify rapid changes in an auditory stimulus (Shinn et al., 2009). Temporal resolution is often assessed via gap detection tests, which require the listener to identify breaks in noise or between tones (Shinn et al., 2009). Deficits in temporal processing can lead to abnormal phonological development and associated reading and language disorders (Whitelaw, 2008).

Several commercially available tests of temporal processing abilities include the following temporal patterning tests: (a) the Pitch Pattern Sequence Test, (b) the Duration Patterns Test, (c) the FPT, (d) the Intensity Pattern Sequence Test, (e) the Auditory

Fusion Test, and (f) the Psychoacoustic Pattern Discrimination Test. Additionally, there are several available tests of temporal resolution, including the Gaps-In-Noise test and the Random Gap Detection Test (Emanuel, 2002; Shinn et al., 2009; Tillery, 2009; Whitelaw, 2008).

Dichotic listening tests. Dichotic speech tests present different stimuli (numbers, words, or sentences) to each ear simultaneously (ASHA, 2005; Bellis, 2003; DeBonis & Moncrieff, 2008; Emanuel, 2002; Whitelaw, 2008). The listener is then asked either to attend to and repeat the stimulus presented to one ear while ignoring the stimulus presented to the opposite ear (binaural separation), or to attend to and repeat the stimuli presented to both ears (binaural integration) (ASHA, 2005; Bellis, 2003; DeBonis & Moncrieff, 2008). The stimuli used for dichotic testing vary in difficulty from simple stimuli, such as digits or single words, to more complex stimuli, such as complete sentences.

Dichotic listening tests allow audiologists to measure the maturation of the CANS (DeBonis & Moncrieff, 2008). Often times when children are assessed using dichotic listening tasks, they will present with a right ear advantage (REA) due to the nature and maturation of the underlying neural pathways of signal transmission. Specifically, the contralateral afferent neural pathways of the CNS are stronger and more numerous than the ipsilateral afferent neural pathways. During dichotic testing, the stronger contralateral pathways suppress the weaker ipsilateral pathways. In order for verbal stimuli to be decoded, they must arrive in the left (language-dominant) hemisphere. Verbal stimuli presented to the right ear will take the dominant contralateral pathway directly to the left hemisphere for decoding; however, verbal stimuli presented to the left ear will cross over

to the right hemisphere via the dominant contralateral pathway. These stimuli must then cross over to the left hemisphere by way of the corpus callosum in order to be processed. As a result of the "easier" route and less crossover required by stimuli presented to the right ear, children will display a REA on dichotic listening tasks until maturation of the central system is complete around age 11 or 12, as myelination of the corpus callosum continues through early adolescence (Bellis, 2003; Whitelaw, 2008).

Several commercially available dichotic speech tests include: (a) the Dichotic Digits Test, (b) the Staggered Spondaic Word Test, (c) the CST, (d) the Dichotic Consonant Vowel Test, (e) SSI with Ipsilateral Competing Message, (f) Dichotic Sentence Identification, (g) the SCAN-C Test for Auditory Processing Disorders in Children—Revised, (h) Competing Words, (i) the SCAN-A Test for Auditory Processing Disorders in Adolescents and Adults, and (j) the Dichotic Rhyme Test (Bellis, 2003; Emanuel, 2002; Tillery, 2009).

Monaural low-redundancy speech perception tests. A monaural low-redundancy task uses a speech signal that is distorted or altered in some way (e.g., filtered, time compressed, presented with background noise, etc.) to reduce the inherent redundancy of the signal, thereby making it more difficult to understand (ASHA, 2005; Bellis, 2003; DeBonis & Moncrieff, 2008; Emanuel, 2002; Whitelaw, 2008). Monaural low redundancy tasks assess the listener's auditory closure abilities (i.e., the ability of the CNS to "fill in the blanks"), and his or her ability to make auditory discriminations with portions of the signal missing or distorted (Bellis, 2003). Often times, individuals with APD will excel when asked to discriminate speech in a quiet listening environment, but

will demonstrate difficulties when the signal is presented in addition to competing noise (e.g., background noise), or the signal is distorted or altered in some way (Bellis, 2003).

Several commercially available tests of monaural low-redundancy speech perception include: (a) Time-Compressed Speech with and without reverberation, (b) Ivey Filtered Speech, (c) Speech-in-Noise tests (e.g., Pediatric Speech Intelligibility and Selective Auditory Attention tests), (d) Phonetically Balanced Kindergarten in Noise test; (e) SSI with Ipsilateral Competing Message, (f) SCAN-C Test for Auditory Processing Disorders in Children—Revised, (g) Filtered Words, (h) SCAN-A Test for Auditory Processing Disorders in Adolescents and Adults, (i) Auditory Figure Ground; (j) Screening Test for Auditory Processing Disorders, and (k) the LPFST (Emanuel, 2002; Tillery, 2009).

Diagnosis

Following test administration, the patient's total score for each test is classified as normal or abnormal upon comparison to age-appropriate normative scores. The lower limits of normal are set two standard deviations below the mean score in order to maintain the necessary sensitivity and specificity of the test (AAA, 2010). APD is diagnosed by an audiologist after the patient scores two or more standard deviations below the mean score for at least one ear on two or more tests of AP ability, or after the patient scores three standard deviations or more below the mean on one test (AAA, 2010; ASHA, 2005; DeBonis & Moncrieff, 2008). Comparing the patient's scores across all categories allows the audiologist to determine areas of relative strengths and weaknesses, which can help guide the resulting recommendations and intervention (AAA, 2010).

Intervention

After a diagnosis of APD has been made, the patient should receive individualized intervention from a multidisciplinary team so that not only will the individual's auditory needs be targeted, but any areas of co-morbid dysfunction that fall outside the audiologist's scope of practice will be targeted as well (e.g., attention difficulties, language disorders, etc.) (AAA, 2010; ASHA, 2005; Bellis, 2003; Young, 1985). Areas addressed during intervention should include the areas of weakness revealed as a result of testing, as well as those revealed through case history interview and patient observation (ASHA, 2005).

Controversies in Current Practice

Academic and clinical preparation. In a 1998 survey, Chermak, Traynham, Seikel, and Musiek surveyed practicing audiologists to evaluate their current AP assessment practices, and how those practices were affected, if at all, by their academic preparation. Surveys from 179 audiologists with a mean of 13.3 years in practice (range: 1-38 years) were analyzed. Of these, 41% of respondents reported assessing APD in their practices. Seventy-eight percent of respondents revealed a satisfaction rating of less than 50% regarding the amount of preparation they were given in their graduate education specific to the assessment and diagnosis of APD. In fact, 80% of respondents revealed they did not complete any course explicitly dedicated to APD. The mean number of clock hours earned in the assessment of APD in children, adults, and the elderly was 3.0 hours on campus and 4.1 hours in the fellowship year. According to Chermak et al. (1998), these results suggested that graduate programs were not adequately preparing students to clinically assess and diagnose APD.

A follow-up survey was conducted by Chermak, Silva, Nye, Hasbrouck, and Musiek in 2007. Specifically, the authors' goal was to determine whether or not there was any improvement in academic preparation specific to APD following the shift in the field of audiology to the (entry-level) doctoral degree. Responses to a questionnaire from 90 audiologists with a mean of 19.4 years in practice (range: 1-42 years) were analyzed. Of these, 27% of respondents reported assessing APD in their current practice. In this survey, only 31% of respondents revealed never taking a course explicitly devoted to APD, a decrease from the 80% reported in the previous survey. Additionally, there was a very slight increase in the number of clock hours logged in the assessment of APD in children, adults and the elderly. A mean of 8.3 hours were obtained on-site and 4.6 hours were earned off-site. Regardless of these changes, the authors concluded that the still-limited coursework and clinical experience related to APD is not conducive to mastering the methodology of assessing and diagnosing APD.

Both the 1998 and 2007 surveys cited a 1997 telephone survey conducted by Sykes, Tucker, and Herr, in which a faculty member/clinical supervisor from each of 40 randomly-selected audiology graduate programs was surveyed regarding the importance their program places on the following areas of audiology: hearing aids, cochlear implants, tinnitus, vestibular disorders/dizziness, and APD. Alarmingly, the authors found that overall, the faculty members ranked the assessment and intervention of APD as the least important of the aforementioned five areas of audiology. Perhaps this relative unimportance placed on APD compared to other areas of audiology by academic personnel directly influenced the limited academic preparation found across audiology graduate programs in the two aforementioned studies by Chermak et al. (1998, 2007).

Lack of appropriate education and clinical preparation relative to APD could potentially result in a lack of complete understanding of the origin, presentation, and implications of APD. This is functionally significant, as it might yield clinicians who are unprepared to select and correctly administer an appropriate AP test battery. Improper test administration could potentially lead to the over- or under-diagnosis of APD.

Lack of a "gold standard". At present, there is no "gold standard" by which to measure the efficiency of AP tests; there is no definitive, objective measure to validate or discredit the accuracy of any test battery used to assess APD (Bellis, 2006; Emanuel, 2011). For example, magnetic resonance imaging (MRI) cannot be performed to confirm or rule out the presence of APD the way it can be used to identify or deny the presence of a medium-to-large sized acoustic tumor, as predicted by results of auditory brainstem response (ABR) testing. As a result, researchers have taken one of two approaches to validate APD testing: measuring test validity against individuals suspected of having APD, or measuring test validity against subjects with confirmed and well-defined CNS lesions (DeBonis & Moncrieff, 2008; Musiek & Chermak, 1994). While the former option does not account for co-morbid factors that may impact the outcome and thereby validity of the test or test battery, the latter fails to address diffuse brain lesions that contribute to AP dysfunction (Cecace & McFarland, 1998; DeBonis & Moncrieff, 2008).

Because we are currently without an objective "gold standard" by which to cross-check behavioral diagnoses of APD, it is imperative that behavioral tests are administered in such a way to increase their reliability (i.e., repeatability of test results) (Bellis, 2003). When administering any behavioral test, ASHA (2005) states that the test methods, including test conditions, directions, scoring and analysis, the use of reinforcement, and

additional procedural variables, must be consistent with those used to standardize the test or as described in the test manual and/or relevant literature (ASHA, 2005). When test methods are not held constant across all individuals, there is a risk for compromising both the results and the test reliability of the evaluation (Young, 1985). When test reliability is poor, there is a higher incidence of misdiagnosis (DeBonis & Moncrieff, 2008).

According to Bellis (2003), factors that can affect a test's reliability include both patient and procedural variables. Patient variables, which are factors directly related to the patient or the disorder, include: (a) patient age, (b) overall health, (c) attention, (d) intelligence, (e) language skills, and (f) related disorder(s). Procedural variables, or "errors of measurement" (Bellis, 2003, p. 200) relate to the test in and of itself, and include elements such as: (a) calibration, (b) practice effects, and (c) ceiling and floor effects. It is this author's opinion that there is a third category of variables, tester variables, that also has the potential to affect a test's reliability.

Tester Variables

Number of test items. According to Thornton and Raffin (1978), one factor that affects test variability is the number of items included in the test. Specifically, the authors emphasized that inconsistent use of the number of test items administered hinders the clinician's ability to compare test results across a group of subjects. Furthermore, it limits the test administrator's ability to confidently assert that the outcome score is the individual's *true* score. Thornton and Raffin (1978) retrospectively studied the results of 4120 administrations of the 50-word Central Institute for the Deaf (CID) Auditory Test W-22. Thornton and Raffin (1978) divided each 50-word list used in the study into randomized 25- and 10-word lists, and subsequently scored each test based on the

original responses given for each test item. The authors compared the subjects' scores across the 50-, 25-, and 10-word lists to determine the effect the number of test items had on test outcome, with the assumption that the 50-word list would yield the most accurate representation of the subjects' true performance. The authors found that the standard deviations of the scores were inversely related to the number of test items, in that the standard deviation (variability) increased as the number of test items decreased. Specifically, the authors found a standard deviation of 8.22% on the 25-word test, and a standard deviation of 13.51% on the 10-word test.

It is therefore assumed that not only will a greater number of test items yield a response closest to the individual's "true" score, but that it is impossible to compare scores to normative results if the same number of test items was not used during both assessments.

Repetition of test items answered incorrectly. To this author's knowledge, no studies directly examining the effect of repeating incorrectly answered test items on test outcome have been conducted. There have been, however, numerous psychological studies conducted to examine an individual's test-taking behavior that can provide information as to what could possibly occur as a result of allowing incorrectly answered test items to be repeated.

According to Rowley and Traub (1977), individuals taking a test will either: (a) answer correctly as a result of actually having knowledge of the test item; (b) not answer, or omit, the question; or (c) guess randomly. The random guess will result in either a correct or incorrect answer. The author of the present study proposes that, based

on the aforementioned, there are several scenarios that can occur when repetitions of incorrectly answered test items are included in testing, specifically:

- The person did not hear the stimulus correctly during its first presentation. Upon repetition of the stimulus, the person will answer the item correctly.
- The person truly has APD and believed his/her incorrect answer during the stimulus' first presentation. The individual will incorrectly answer the test item again when it is presented for the second time.
- The person guessed the answer incorrectly during the first presentation. When the stimulus is presented for a second time, the person will either guess the answer correctly due to chance (Seashore, Wesman, Doppelt, Gelink, & Ricks Jr., 1954), or the person will guess incorrectly.

Additional studies have shown that guessing, and the likelihood to guess or not to guess, is related to the individual's personality (Betts, Elder, Hartley, & Trueman, 2009; Rowley & Traub, 1977; Swineford & Miller, 1953) and age (Huff, Meade, & Hutchison, 2011). Furthermore, an individual's likelihood to guess or not is associated with the instructions given to the individual (Swineford & Miller, 1953). Specifically, research has shown that individuals tend to respond to fewer items when they are explicitly told not to guess, and respond to more items when they are encouraged to guess (Swineford & Miller, 1953). Additionally, and interestingly, adults are more likely than children to guess all the time, regardless of the instructions given (Huff, Meade, & Hutchison, 2011).

It is unclear at the present time whether or not the use of repetitions will affect test outcome and, if so, whether or not this modification enables audiologists to more accurately identify the presence of APD.

Functional Significance

According to Cacace & McFarland (1998), a wealth of intrinsic and extrinsic factors can influence an individual's performance on a test. In order to assert that poor performance is the result of one factor in particular, any additional factors must be held constant. In an effort to most accurately diagnose poor auditory processing abilities without presently having a "gold standard" by which to confirm the diagnosis, audiologists must hold test administration factors constant to eliminate non-patient variables from interfering with the overall test result. For the most part, APD is diagnosed based on subjective test results, creating an inherently high amount of variability in terms of diagnosis. Additionally, clinicians are using different standards and criteria to diagnose APD, potentially due to limited understanding of APD resulting from limited graduate coursework and clinical exposure. Variability in test administration procedures not only leads to confounding variables (subject and clinician), but reduces the test reliability, and thereby the diagnostic significance of the test. According to Bellis (2003), it is the clinician's responsibility to account for variability associated with AP evaluations, throughout both the exam and interpretation of test results. Additionally, Bellis (2003) calls for the need for further research to more fully understand potential causes of variability and how to improve the reliability of tests of AP ability.

Anecdotally and in clinical observation it appears that, due to time constraints, inattentive patients, etc., behavioral tests of APD are not administered in strict accordance to published guidelines. It is unknown at this time if using different scoring procedures (including a different number of test items) and/or repeating incorrectly answered test items affects the outcome of the test. Thus, this study serves as an attempt

to determine whether or not such clinician-controlled “tester” variables affect the test outcome (pass or fail), and thereby potentially, the ultimate diagnosis of APD.

Chapter 3

Methodology

Participants

All protocols in the present study were approved by the Towson University Institutional Review Board (IRB) prior to recruiting participants (Appendix A). Thirty-three native English-speaking participants with a minimum age of 50 years participated in this study. Participants were recruited through the use of a flier (Appendix B), Towson University faculty email databases, and word of mouth. Participation in the study was voluntary, and consent was obtained from all participants prior to the start of testing (Appendix C).

Case history information was obtained orally from all participants prior to testing. Questions regarding overall health, hearing acuity, and history of ear surgery, major surgery, and stroke/neurodegenerative disease were asked. Any individual who reported significant otologic or medical history was disqualified from further testing, with the reason for exclusion indicated on the thesis checklist form (Appendix D). Individuals with no significant history were then assessed using the Mini-Mental State Exam (MMSE) to ensure normal cognitive function and to rule out any potential influence of decreased cognition on test outcome (Appendix E). Any participant who scored below normal limits on the MMSE (≤26) was released from testing (Alzheimer's Society, 2013).

Following successful completion of the MMSE, tympanometry was conducted on all participants using a GSI-61 TympStar tympanometry bridge. Participants with a mobile tympanic membrane (0.2-1.8 ml) and peak pressure no poorer than -150 daPa were included in the study (Cox et al., 2008; Schlauch & Nelson, 2009). Air and bone

conduction pure tone testing was completed using a GSI-61 two-channel audiometer. All participants had hearing thresholds of 25 dB HL or better at all octave band frequencies from 500 to 4000 Hz, and 55 dB HL or better at 8000 Hz, with no significant asymmetry between ears (Cox et al., 2008). For the purposes of this study, asymmetry was defined as: (a) a difference of ≥10 dB HL between ears at three test frequencies, (b) a difference of ≥15 dB HL between ears at two test frequencies, or (c) a difference of ≥20 dB HL between ears at one test frequency (Cohn et al., 1999). Additionally, none of the participants had any observable air-bone gaps, defined as a difference of >10 dB HL between air and bone conduction thresholds for each ear, at any of the test frequencies (Schlauch & Nelson, 2009).

Procedure

All participants who met the aforementioned criteria were then given one test from each of the three major categories of AP assessment (temporal processing, dichotic listening, and monaural low-redundancy speech perception). All tests of APD were administered via compact disc (CD). An external CD player routed through both channels of the audiometer was used to present all recorded materials. Calibration was performed before each test so that the VU meter peaked at 0 dB HL for both channels of the audiometer using the calibration tone provided on the CD.

Test and ear order were randomized for each participant. For all tests, each participant was administered the standard number of test items first. Following completion of all test items, any items answered incorrectly were repeated and marked separately. The test was then scored in the following four conditions: (1) standard number of test items, not including repetitions; (2) standard number of test items, corrected for

repetitions; (3) adapted (shortened) number of test items, not including repetitions; and (4) adapted (shortened) number of test items, corrected for repetitions. The adapted number of test items is a number less than the standard number administered for each test, under the premise that clinicians are likely to use fewer test items rather than a greater number of test items when deviating from the standard number during an assessment. The adapted number of test items was selected based on what the author has observed in clinical practice. Ultimately, all conditions were compared to published normative data. Test procedures specific for each test are explained in the following section.

APD Testing

All tests were administered on Towson University's campus in a double walled sound treated test suite. All tests were administered using a Grason Stadler Inc. 61 (GSI-61) two-channel audiometer and Etymotic Research-3A (ER-3A) insert earphones. Three tests of AP abilities, the FPT (Musiek & Pinheiro, 1987), CST (Willeford & Burleigh, 1994), and LPFST (Auditec of St. Louis), were included in this test battery. These tests were selected based on results from the aforementioned survey by Emanuel et al. (2011), which indicated that the FPT, CST, and LPFST were three of several popular tests most often selected by clinical audiologists to assess APD. Furthermore, each of these tests have well-documented sensitivity and specificity. The FPT test has been proven 83% sensitive and 88-95% specific in detecting cerebral hemispheric and corpus callosum lesions in individuals 8 years of age and older (Bellis, 2003; Musiek et al., 2011; Musiek & Pinheiro, 1987). The CST has been shown to be 56-75% sensitive, although only 10% specific, to cortical and brainstem lesions in individuals 8 years of age and older (Musiek, 1983; Musiek et al., 2011). The LPFST has proven to be 65-75% sensitive and 72%

specific in detecting brainstem and cortical lesions in individuals 7 years of age and older (Bellis, 2003; Musiek et al., 2011).

Frequency pattern test. The FPT "consists of 880-Hz (low) and 1122-Hz (high) tones that are 200 msec in duration, have an interstimulus interval of 150 msec, and a 10-msec rise fall time" (Musiek, 2002, p. 58). Individuals without APD are able to differentiate between the low and high tones without much difficulty, whereas listeners with APD may be unable to detect the differences between these frequencies (Bellis, 2006).

Directions. A standard set of directions was developed based on a description by Musiek (2002), as follows: "You are going to hear a series of beeps. Some of the beeps will be high pitched, like this (clinician hums high pitch), and some of the beeps will be low pitched, like this (clinician hums low pitch). You will hear a series of three beeps. I want you to tell me the pattern of the three beeps that you hear. For example, if you heard (clinician hums high-low-high), that would be 'high-low-high.' If you heard (clinician hums low-high-low), that would be 'low-high-low.' Let's practice". Several examples were then provided until it was apparent that the participant understood the task at hand. Following the examples, the clinician stated, "We are going to begin the test. Remember, after each series of beeps, tell me the pattern of the three tones that you heard."

Procedure. Thirty test items were delivered monaurally to the participant's test ear at a presentation level of 50 dB SL re: 1000 Hz threshold (Bellis, 2003; Musiek, 2002). Upon completion of the standard number of 30 test items, items that were originally marked incorrect (uncorrected responses) were repeated one time each (corrected responses). Testing was completed for the right and left ears individually.

Scoring. The test was scored in a percent correct form (Appendix F) (Bellis, 2003). Reversed responses (e.g., the participant responds "low-high-low" when the presentation was "high-low-high") were considered incorrect per Musiek (2002). If the participant responded with more than three tones, even if the first three were correct (e.g., the participant responded "low-high-low-low" when the presentation was "low-high-low"), the response was considered incorrect (Musiek, 2002). A passing score on this test for an adult is ≥80% for each ear (Bellis, 2003). Scoring for purposes of this study was as follows, for each ear:

Condition 1. The test was scored based on the participant's responses to all 30 test items using uncorrected responses.

Condition 2. The test was scored based on the participant's responses to all 30 test items using corrected responses.

Condition 3. The test was scored based on the participant's responses to the first 15 test items using uncorrected responses.

Condition 4. The test was scored based on the participant's responses to the first 15 test items using corrected responses.

Competing sentences. The CST is a test of binaural separation, or the ability to attend to the signal of interest presented to one ear while simultaneously ignoring the distracting stimulus presented to the other ear (Bellis, 2006). This test contains pairs of sentences similar in length and content that are presented to both ears simultaneously. It is intended that the right ear stimulus is the target sentence for 10 sentence pairs, and that the left ear stimulus is the target sentence for an additional 10 sentence pairs (Willeford & Burleigh, 1985).

Directions. The participant was instructed as follows, based on a description by Bellis (2003): "You will hear two different sentences at the same time. You will hear one sentence in your right ear and one sentence in your left ear. I want you to listen only to the sentence that you hear in your (target) ear. Point to your (target) ear. (Participant points to target ear). Good. Remember, repeat back only the sentence you hear in your (target) ear."

Procedure. Ten sentences with the right ear as the target ear and ten sentences with the left ear as the target ear were administered for scoring. The target sentence was presented at 35 dB SL re: PTA, and the competing sentence was presented at 50 dB SL re: PTA (Bellis, 2003). Sentences that were originally marked partially or completely incorrect (uncorrected responses) were repeated one time each (corrected responses) following administration of all test items.

Scoring. Willeford and Burleigh (1994) shy away from a strict method of scoring this test. Specifically, these authors allow paraphrased responses to the test sentences so long as no significant changes in the sentence meaning were made as a result of the variation. It should be noted that an alternative to this scoring procedure has been proposed in an effort to eliminate clinician error and thereby improve between-test (specifically, between-clinician) reliability. As suggested by Musiek and Pinheiro (1985), each sentence should be divided into quadrants worth 25% of the sentence score, or 2.5 points out of a total possible 10 per sentence. Each quadrant will be scored word for word. As a result, it is possible for a person to score 0, 2.5, 5, 7.5, or 10 out of 10 possible points. When the scores of all 10 sentences are combined, they generate a percentage

correct score. A passing score on this test is ≥90% for each ear (Bellis, 2003). Scoring for purposes of this study was as follows, for each ear:

Condition 1. The test was scored based on the participant's responses to all 10 test items using uncorrected responses.

Condition 2. The test was scored based on the participant's responses to all 10 test items using corrected responses.

Condition 3. The test was scored based on the participant's responses to the first 5 test items using uncorrected responses.

Condition 4. The test was scored based on the participant's responses to the first 5 test items using corrected responses.

Conditions 1-4 were scored two times each, one time using the scoring method recommended by Willeford and Burleigh (1994), and one time using the scoring method recommended by Musiek and Pinheiro (1985) (Appendix G). Results from all conditions were compared to normative data for analysis.

Low-pass filtered speech. The 1000 Hz cutoff, male speaker version of the LPFST from Auditec of St. Louis was used in this study. The 1000 Hz filter option was selected because it is the most recommended and observed by the author in clinical practice, and because the 500 Hz option is too difficult, even for listeners with normal hearing (Bellis, 2006). This test is comprised of NU-6 words that have been low-pass filtered, meaning that information above a specified cut-off frequency (in this case, information above 1000 Hz), is removed from the signal, simulating a high-frequency hearing loss and reducing the intelligibility of the signal (Bellis, 2006; Willeford & Burleigh, 1985). Typical listeners can 'fill in the blanks' and understand the message in

spite of the missing pieces; listeners with APD, however, often struggle to do so (O'Beirne et al., 2012).

Directions. Each participant was instructed as follows, based on a description by Bellis (2003): "You will hear a series of words that may be difficult to understand. Each word will be presented one at a time. I want you to repeat each word as you hear it."

Procedure. Fifty words per ear were administered monaurally to each participant at a presentation level of 50 dB HL (Bellis, 2003). Items that were originally marked incorrect (uncorrected responses) were repeated one time each (corrected responses) following administration of all test items.

Scoring. This test is scored in terms of percent correct (Appendix H). A passing score for an adult on this test is ≥78% (Bellis, 2003). Scoring for purposes of this study was as follows, for each ear:

Condition 1. The test was scored based on the participant's responses to all 50 test items using uncorrected responses.

Condition 2. The test was scored based on the participant's responses to all 50 test items using corrected responses.

Condition 3. The test was scored based on the participant's responses to the first 25 test items using uncorrected responses.

Condition 4. The test was scored based on the participant's responses to the first 25 test items using corrected responses.

Planned Analyses

This study utilized a repeated-measures design, in that each participant underwent each test condition that was ultimately assessed. This design was chosen for this

experiment in an effort to decrease unsystematic variation within the design of the study. Multivariate Analysis of Variance (MANOVA) was used to determine if using fewer test items and if repeating test items originally answered incorrectly have an effect on the outcomes of three tests of APD. A dependent/paired samples t-test was used to determine the effects of varying scoring methods on the outcome of the CST. Interaction effects were measured to determine what effect, if any, a combination of the variables (number of test items, repetition of test items, and/or scoring methods) had on the test scores.

Chapter 4

Results

Participants

Thirty-seven adults (13 male, 24 female) were recruited for participation in this study. All volunteers presented with normal case history (no known hearing loss, and no history of ear surgery or neurodegenerative disease) and cognitive status (as determined by scores within normal limits on the MMSE). Four of the 37 volunteers (3 males, 1 female) were excluded from the study due to degree of hearing loss that fell outside the range defined as "normal" for this study. Data was collected and analyzed from the remaining 33 participants (10 male, 23 female). Mean ages for the participants who completed the study were 57.8 years (*SD* = 4.59) for the males (range: 51-64) and 57.2 years (*SD* = 4.58) for the females (range: 50-65).

Audiometric Thresholds

All 33 participants had normal hearing (defined as 25 dB or better at all octave band frequencies from 500 to 4000 Hz, and 55 dB or better at 8000 Hz) and mobile tympanograms (defined as compliance between 0.2 and 1.8 ml, with peak pressure no poorer than -150 daPa) bilaterally. Mean pure tone audiometric thresholds per frequency and ear for the male and female participants are displayed in Table 1 below.

Table 1

Mean Pure Tone Air Conduction Thresholds Per Ear for Male and Female Participants

Gender	Ear	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Male	Right	14 (7.38)	17 (6.75)	15.5 (8.32)	15 (8.82)	23.5 (14.54)
	Left	14.5 (6.85)	16 (6.58)	16.5 (7.84)	17 (5.87)	26 (12.65)
Female	Right	12.30 (5.81)	11.96 (6.35)	13.26 (6.50)	12.83 (6.88)	19.35 (13.25)
	Left	12.39 (6.55)	10.65 (5.29)	12.39 (4.74)	13.91 (7.97)	17.83 (11.16)

Note. The mean pure tone thresholds in dB HL by frequency and ear for male and female participants are displayed in the table above, with standard deviation values contained in parentheses.

Auditory Processing Tests

Gender Effects. One-way Analysis of Variance (ANOVA) revealed no significant effect of gender on the outcome of any of the three tests of APD used in this study ($p > .05$). As a result, gender was collapsed for all subsequent analyses.

Ear Effects. Repeated-measures MANOVA revealed no significant main effects of ear on test score ($p > .05$). Data were collapsed for ear for all remaining analyses.

Scoring Method. Paired samples t-tests were used to determine whether or not there was a significant difference in test outcome when scoring the CST using the Willeford and Burleigh (1994) method as compared to the Musiek and Pinheiro (1985) method. No significant differences were found between the two scoring methods in any of the test conditions, as shown in Figure 1 below. As a result of this finding, subsequent analyses were conducted using scores obtained from the Willeford and Burleigh (1994) scoring method only.

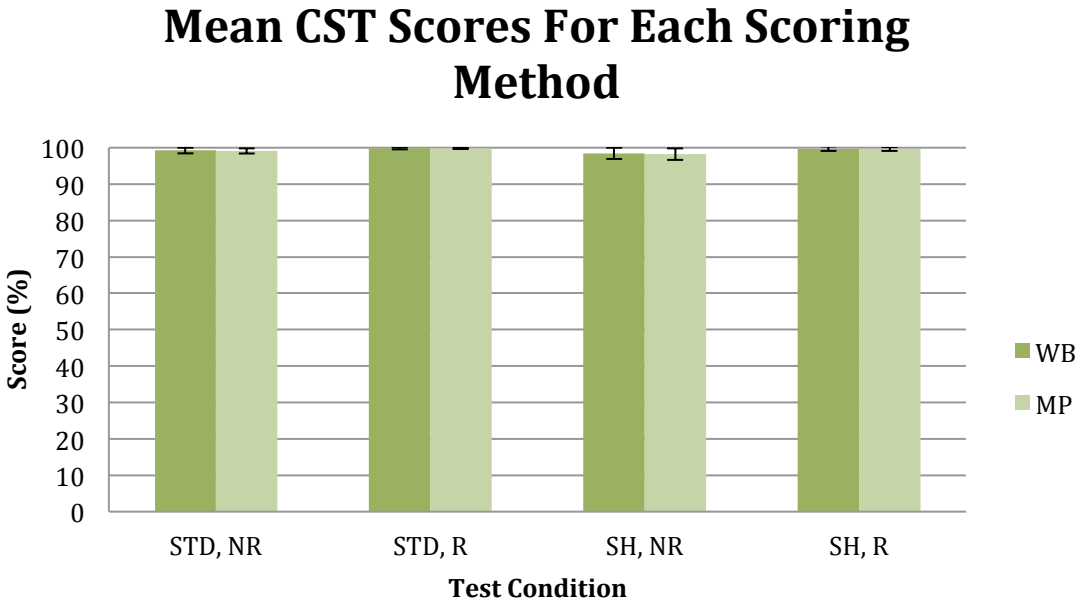


Figure 1. Mean test scores for the CST in all four test conditions based on two different scoring techniques are displayed above. Error bars represent two standard errors above and below the mean. STD, NR = standard (long) number of test items, no repetitions used; STD, R = standard (long) number of test items, with repetitions; SH, NR = adapted (shortened) number of test items, no repetitions used; SH, R = adapted (shortened) number of test items, with repetitions; WB = Willeford and Burleigh (2004) scoring technique; MP = Musiek and Pinheiro (1985) scoring technique.

Main Effects. Repeated-measures MANOVA was conducted to examine the effects of test (3 levels), length (2 levels), and repetitions (2 levels) on outcome score for all three tests of AP ability. Analysis revealed a significant main effect of test, $F(2, 31) = 196.44$, $p < .0001$, on overall score. Mean outcome scores for all participants were significantly different for the three tests used in this study, as shown in Figure 2 below.

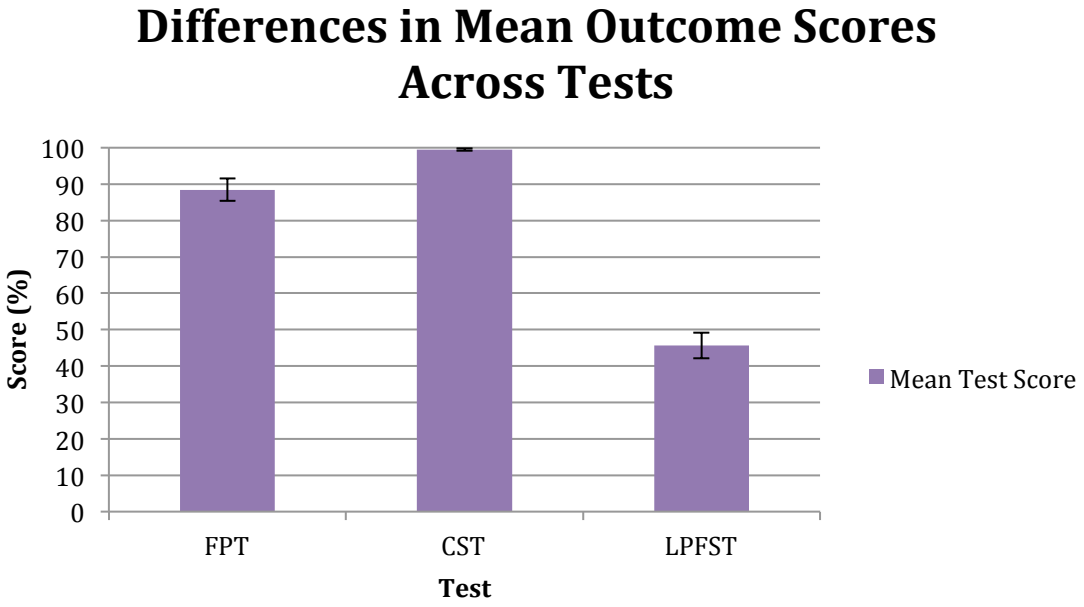


Figure 2. Differences in mean test score for participants across the FPT, CST, and LPFST are represented to show the main effect of test on outcome score. Error bars represent two standard errors above and below the mean. FPT = Frequency Pattern Test; CST = Competing Sentences Test; LPFST = Low-Pass Filtered Speech Test.

Specifically, participants' mean test score was the highest for the CST (99.51%), followed by the FPT (88.47%). Participants' mean test scores were lowest for the LPFST (45.64%). This main effect was not surprising given the fact that these are three distinct tests of APD designed to assess different areas of AP ability.

Repeated-measures MANOVA additionally revealed a main effect of repetition, $F(1, 32) = 73.83$, $p < .0001$, on test score, which can be seen in Figure 3 below.

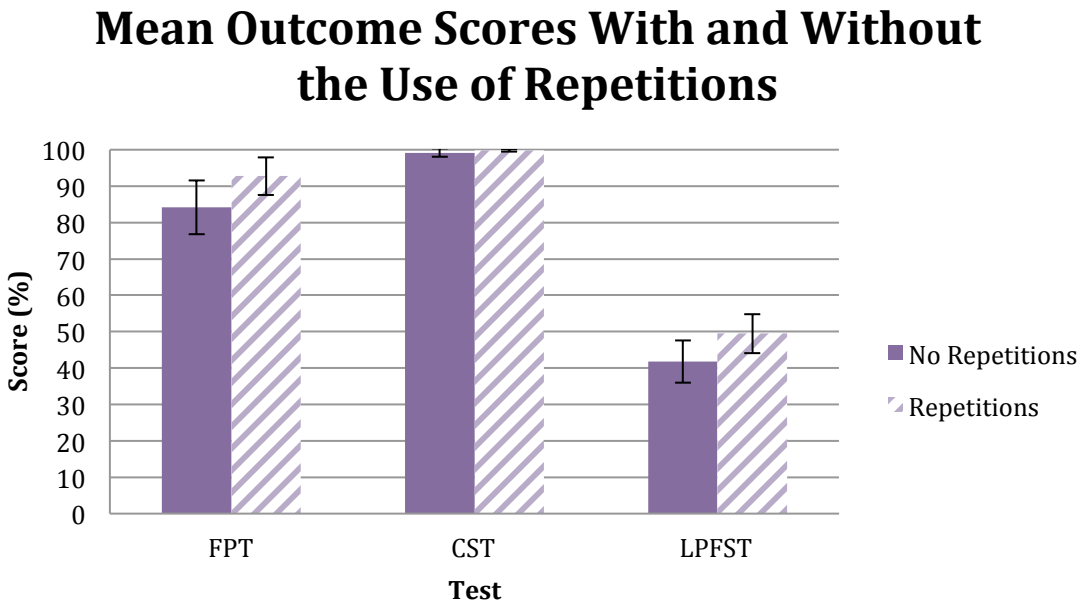


Figure 3. Mean outcome scores for each test are represented across two conditions: without repetitions of incorrectly answered test items, and including repetitions of incorrectly answered test items. Error bars represent two standard errors above and below the mean. FPT = Frequency Pattern Test; CST = Competing Sentences Test; LPFST = Low-Pass Filtered Speech Test.

Interactions. Interactions between test and use of repetitions, $F(2, 31) = 39.80$, $p < .0001$, as well as number of test items and use of repetitions, $F(1, 32) = 8.48$, $p = .006$, were revealed. To better explore these results, individual repeated measures MANOVAs were conducted for each test.

FPT. Repeated-measures MANOVA was conducted to examine the effects of length (2 levels) and repetitions (2 levels) on outcome score for the FPT. Results revealed a significant main effect of repetition, $F(1, 65) = 45.57$, $p < .0001$, but no main effect of length ($p = .97$). Additionally, results revealed no interactions between number of test items and use of repetitions ($p = .72$). Mean outcome scores on the FPT were significantly greater overall when repetitions were used (92.77%) compared to when repetitions were not used (84.16%).

CST. Repeated-measures MANOVA conducted to examine the effect of length (2 levels) and repetitions (2 levels) on the CST revealed no main effect of repetition (p = .10). Additionally, no main effect of length (p = .60) was revealed, as shown in Figure 4 below.

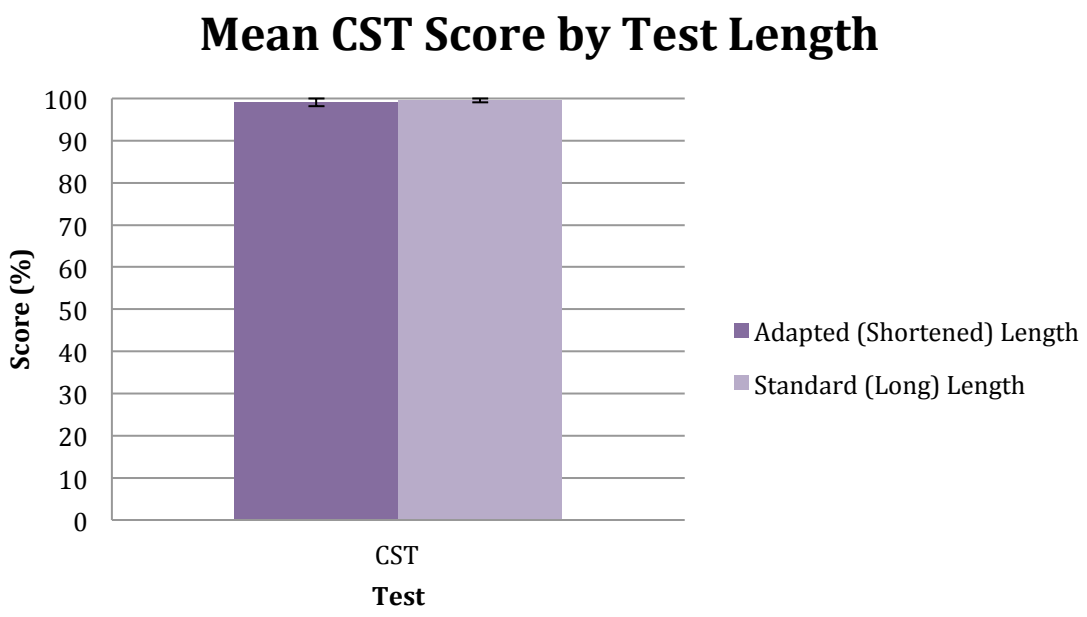


Figure 4. Mean test scores for the CST, administered with an adapted (shortened) number of test items and the standard (long) number of test items, are shown above. Error bars represent two standard errors above and below the mean. Mean test scores were not significantly different when established using an adapted number of test items compared to the standard number of test items. CST = Competing Sentences Test.

Additionally, individual MANOVA conducted on the CST data revealed no interaction between number of test items used and use of repetitions (p =.10).

LPFST. Results from the repeated-measures MANOVA using data from the LPFST to examine the effects of length (2 levels) and repetitions (2 levels) revealed a significant main effect of repetitions, $F(1, 65) = 112.40$, $p < .0001$. No significant main effect of length was revealed (p = .78). Results also revealed a significant interaction between number of test items used and use of repetitions, $F(1, 65) = 18.01$, $p < .0001$,

such that the effect of repetitions is larger for the adapted (shortened) number of test items versus the standard (long) number of test items, as shown in Figure 5 below.

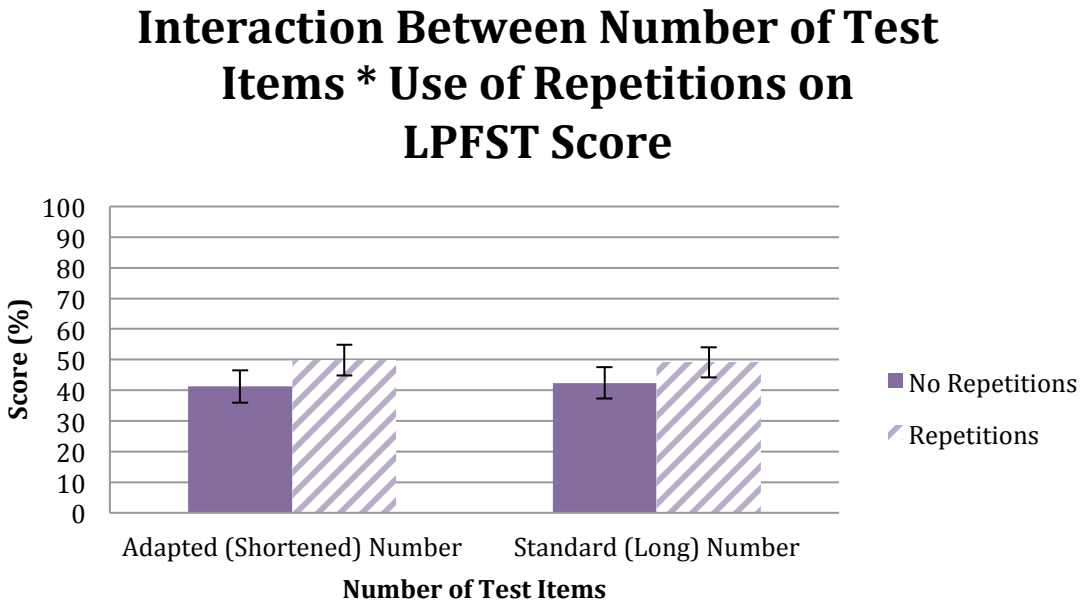


Figure 5. A bar graph depicting the interaction between number of test items used and use of repetitions. Error bars represent two standard errors above and below the mean. The relationship depicted is such that that there was a greater effect of repetition usage for the adapted (shortened) number of test items compared to the standard (longer) number of test items.

Additional Analyses

Univariate ANOVA was conducted on each test to determine if there was a difference in outcome score based on the test list administered and order of the lists, which had been randomized prior to testing. Results revealed no significant main effects of test list or test order, and no interaction between test list and order, for the FPT or CST. Results revealed a significant main effect of list number, as well as an interaction between test list and order, for the LPFST. The main effect of list number, $F(1, 65) = 23.39$, $p < .0001$, is such that mean scores were significantly greater overall for LPFST List 1 (52.32%) compared to List 2 (31.61%). Furthermore, the interaction between list

and order, $F(1, 65) = 4.81$, $p = .03$, is such that when participants were given List 1 followed by List 2, mean test scores decreased substantially from 44.53 to 30.0%. When participants were given List 2 followed by List 1, mean test scores increased substantially from 33.22 to 60.11%. This interaction can be seen in Figure 6 below.

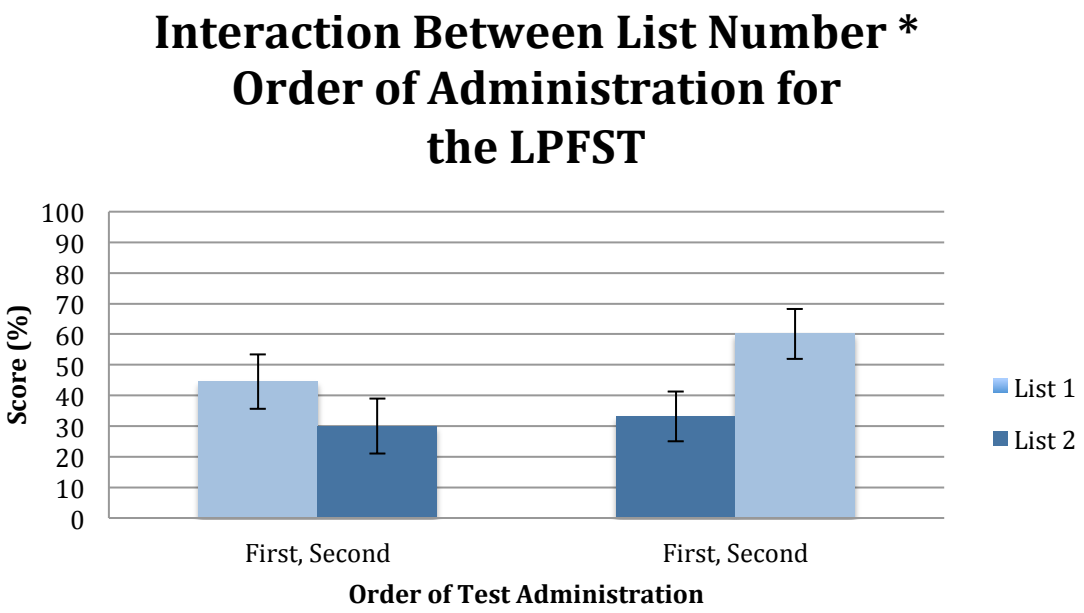


Figure 6. A graph depicting the interaction between list number (1 and 2) and the order of administration (first test administered, second test administered). Error bars represent two standard errors above and below the mean. The interaction is such that when given List 1 followed by List 2, participants' mean test scores decreased substantially. When given List 2 followed by List 1, participants' mean test scores increased substantially.

Chapter 5

Discussion

APD is an impairment of the CANS's ability to process auditory input that is estimated to affect between 17 and 95% of older adults (≥80 years old) (AAA, 2010; Stach et al., 1990). At present, inadequate academic and clinical preparation specific to the assessment and diagnosis of APD, as well as the lack of a "gold standard" of assessment, have created controversy surrounding the diagnosis of APD. As a result, audiologists must strive to maintain the reliability and validity of each test of APD to maintain the diagnostic significance of the test outcome. To do so, audiologists must maintain the same test conditions, directions, scoring, and tester variables that were originally used when the test was standardized (ASHA, 2005).

Recently, several studies have emerged to highlight the need for improved administration and interpretation of tests of APD (e.g., Cacace & McFarland, 2013; Turner, 2013; Wilson & Arnott, 2013). Cacace and McFarland (2013) express the necessity for more uniform test procedures related specifically to the assessment of APD. In fact, the sentiment expressed by Cacace and McFarland (2013) is strikingly similar to one articulated by Bellis (2003) a decade prior, in that external test factors must be held constant in order to improve the overall validity of the test. Similarly, Turner (2013) states that when the variability of individual tests of APD increase, the value of the test battery as a whole diminishes, reducing the diagnostic significance of any resulting diagnosis of APD. Wilson and Arnott (2013) argue that a diagnosis of APD should only be made when the audiologist explicitly states which set of diagnostic criteria were used to make the diagnosis. They propose that some of the apparent over-diagnosis of APD

may be attributable to different clinicians making diagnoses based on different diagnostic criteria. The aforementioned are just three of several recent studies that underline the need for improved APD test administration and scoring procedures, a need initially described over a decade ago.

Bellis (2003) defines patient and procedural variables that can affect the outcome, and thereby overall validity, of tests of APD. It has been proposed by the author of the present study that an additional category of variables, tester variables, also has the potential to affect a test's reliability. It was the goal of this thesis study to determine whether specific tester variables, including number of test items used, repetitions of incorrectly answered test items, and scoring method, significantly affect a test's outcome and thereby potentially, the overall diagnosis of APD in older adults.

Summary of Findings

Test. A main effect of test was found across all three tests of APD used in the present study. This effect was expected, as each test assesses a different area of AP ability, thus explaining why different tests are combined into a single test battery to fully evaluate an individual's AP abilities (Bellis, 2003).

Gender Effect. No effect of gender was present across any of the three tests of APD used in the present study. This finding was not surprising, as studies have reported no significant difference in the prevalence of APD in adult males and females (Cooper & Gates, 1991).

Ear Effect. No effect of ear was shown on any of the three tests of APD administered in the present study. This finding is not surprising, as ear effects are often only seen in young children (Bellis, 2003). Specifically, a REA is often revealed during

dichotic listening assessment of young children (less than 10-12 years of age), as the corpus callosum has not fully maturated at this time (Bellis, 2003; Whitelaw, 2008). Because this study evaluated the AP abilities of older adults, and because we expect the corpus callosum to be fully myelinated by adulthood, it is not surprising that no effect of ear was seen on any of the three tests of AP ability used in the present study.

CST Scoring Method. No significant differences were found between mean outcome scores of the CST calculated using the Willeford and Burleigh (1994) method and those calculated using the Musiek and Pinheiro (1985) method. The lack of a significant finding may be due to the perceived ease of the CST for the older adult population, and thereby, the resulting ceiling effects (Bellis, 2003).

Length. No significant effect of length was shown on any of the three tests of APD used in the current study. This finding was not expected, as the large-scale study by Thornton and Raffin (1978) concluded that administering the same test using varying numbers of test items significantly affects test outcome. The lack of an effect found in the present, small-scale study has significant implications for the clinical assessment of APD. Specifically, if this finding is supported by additional, larger-scale studies conducted in the future, it lends itself to the reduction of overall test time. It has been documented that assessment of APD should not last longer than 45 to 60 minutes to limit patient fatigue, inattention, and decline in motivation (AAA, 2010). Therefore, if additional studies with a larger number of participants are able to support the finding that shortened test lengths do not significantly affect test outcome, it is possible that test time can be reduced without sacrificing reliability.

Repetition. Repetition of incorrectly answered test items was shown to have an effect on two of the tests used in the present study, the FPT and LPFST. A 2011 study by Huff, Meade, and Hutchison found that adults are more likely than children to guess during testing. This allows for the possibility of more variable responses by adults, given the fact that they are likely to guess any unknown answers, whereas responses from children likely do not vary as much due to their tendency to shy away from guessing (Rowley & Traub, 1977). Therefore it is not surprising that by allowing adults the chance to repeat themselves and thereby increase the variability of their responses, the use of repetitions in the present, small-scale study, was found to significantly affect the outcome of two tests of APD.

It was proposed earlier that there were several scenarios that could occur when repetitions of incorrectly answered test items were included during testing, specifically:

- The person did not hear the stimulus correctly during its first presentation. Upon repetition of the stimulus, the person will answer the item correctly.
- The person truly has APD and believed his/her incorrect answer during the stimulus' first presentation. The individual will incorrectly answer the test item again, when it is presented for the second time.
- The person guessed the answer incorrectly during the first presentation. When the stimulus is presented for a second time, the person will either guess the answer correctly due to chance (Seashore, Wesman, Doppelt, Gelink, & Ricks Jr., 1954), or the person will guess incorrectly.

Based on the findings in the present study that scores increased when repetitions of incorrectly answered test items were included in the test score, it is this author's assumption that one or both of the following scenarios occurred:

- The person did not hear the stimulus correctly during its first presentation. Upon repetition of the stimulus, the person answered the item correctly.
- The person guessed the answer incorrectly during the first presentation. When the stimulus was presented for a second time, the person guessed the answer correctly due to chance (Seashore, Wesman, Doppelt, Gelink, & Ricks Jr., 1954).

It is unclear how often each of these two scenarios occurred during the present study, and thereby this author is unable to make a statement regarding whether or not the use of repetitions of incorrectly answered test items lends itself to a more accurate diagnosis of APD. What is clear from the results of this small-scale study is the following implication: if a clinician decides to repeat incorrectly answered test items, and if this is not explicitly allowed per the test manual, there is the possibility that the test outcome may be falsely elevated compared to the participant's true score. As a result, use of repetitions must be held constant with the test's instructions, or site-specific normative data must be collected separately to account for these variations from the standard methodology.

Length * Repetition Interaction. An interaction between length of the test and use of repetitions was found for one of the tests used in the current small-scale study, the LPFST, suggesting that altering more than one test variable can create a statistically significant difference in test outcome. Once again, audiologists must be made aware of such implications and understand the importance of controlling for tester variables. In

doing so, the validity of patient's test results will increase, while the likelihood of false diagnostic outcomes will subsequently decrease.

List Effect. A surprising effect of list was found for the LPFST such that List 1 yielded higher scores than List 2. Additionally, participants performed better when given List 2, the more difficult list, first, followed by List 1. Audiologists should take into consideration that differences found between ears on this test in particular might actually be compounded by the list effect. In the future, additional studies using a larger number of participants should be conducted to confirm or refute this finding.

Clinical Significance

Results of this study, both in the main effects and interactions found, further highlight the need for audiologists to administer and score tests of auditory processing disorder as they were when the tests were originally standardized (ASHA, 2005). If test administration procedures are varied but results are compared to normative data values previously obtained using standard test procedures, there is a chance to increase false diagnostic outcomes and thereby reduce test reliability. According to DeBonis and Moncrieff (2008), this leads to a higher incidence of misdiagnosis, as it makes it increasingly difficult to factor out a true APD from false test scores resulting from poor methodology and improper scoring (Cacace & McFarland, 1998).

Limitations of Present Study

Sample Size. Due to time constraints, this study was limited to the evaluation of the AP abilities of 33 older adults. Ten male and 23 female participants were recruited for this study. In the future, a larger number of adults with a more even male:female ratio should be evaluated.

Recruitment. All older adult participants in the present study were heavily recruited via flyers posted around Towson University and emails to Towson University faculty and staff members. The resulting participant group was fairly homogenous, especially in terms of race/ethnicity and education level. In the future, the AP abilities of a more diverse participant group should be assessed.

Tests Used. Due to the time constraints of this thesis study, only three tests of AP ability were assessed: the FPT, CST, and LPFST. These tests were chosen as they represent one test from each of the three main categories included in AP test batteries: temporal processing, dichotic listening, and monaural low-redundancy speech perception (Emanuel, 2002). It would be helpful to assess the effect of tester variables on additional tests of APD, as the effects are likely to vary across tests, as seen even within this small-scale study.

Future Directions

Future research should focus on assessing the effect of tester variables (those included in this study as well as additional variables) on the outcome of additional tests of APD on a larger group of adult participants. Audiologists must then choose how to administer tests of APD within their clinic: in accordance with established norms, or in a modified manner. If an audiologist decides to administer tests of APD in a manner different from that which was used to standardize the test, it is imperative that the audiologist first collect his or her own normative data to account for this difference in test administration. As evidenced by this study, varying the test administration methods from those expressed in the test's manual or relevant literature can in fact affect the outcome of the test. It would be incorrect and irresponsible to compare scores obtained using

modified test administration methods to normative scores obtained using standard test administration methods.

Conclusions

This small-scale study has shown that varying test administration procedures from those used to standardize tests of APD can affect the test's outcome. Because a diagnosis of APD is made after a patient scores two or more standard deviations below the mean on two or more tests of AP ability, changing the outcome of even one test has the effect to vary the diagnosis of APD. In order to maintain the integrity of an APD diagnosis amid a lack of objective methods available to assess the disorder, audiologists must commit to the use of valid test measures. Therefore, audiologists must administer tests of APD the way in which they were standardized, or in their adapted manner compared to individualized normative data.

APPENDICES

APPENDIX A:
IRB APPROVAL

RENEWED APPROVAL NUMBER: 11-A050R1

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

APPENDIX B:
THESIS RECRUITMENT FLYER

Adult Participants Needed for Auditory Processing Research

WHO?

Native English-speaking **adult males and females (age 50-70 years)** with normal hearing and no history of stroke, neurodegenerative disease, or ear pathology.

**All participants will receive a hearing evaluation as part of the study.*

WHY?

To evaluate the reliability of commonly-used tests of auditory processing disorder. *Auditory processing* is the term used to describe our brain's ability to process what we hear.

WHERE?

All testing will be conducted in Dr. Stephanie Nagle's (Thesis Advisor) laboratory in Van Bokkelen Hall on **Towson University's campus.** Parking information and light refreshments will be provided.

WHEN?

Testing will be conducted throughout the semester. Morning and early afternoon appointments are available on **Mondays** and **Thursdays**. Appointments are also available all day on select **Fridays**. **Evening and weekend** appointments are also available. Total test time is estimated at approximately 1.5 hours.

INTERESTED?

If you fit the above criteria and are willing to volunteer in this study, please contact Maria Pomponio (Audiology Doctoral Candidate) at mpompo1@students.towson.edu at your convenience.

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

APPENDIX C:
INFORMED CONSENT FORM

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 of 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 hears. The study will include both normal hearing and hearing impaired individuals. We need to test your 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 responses to these various sounds. The electrodes are placed on top of the skin (i.e., ear, hand, neck, or clavicle) 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 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 this study will be kept private. In any report published or presented regarding this study there will be no information that will 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) 704-3554. 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 D:
THESIS CHECKLIST

THESIS CHECKLIST

- Consent Form □

- Case History
  - □ Within Normal Limits
  - □ Reason to Exclude: _____

- Mini-Mental State Exam
  - □ Within Normal Limits
  - □ Reason to Exclude: _____

- Otoscopy
  - □ Within Normal Limits
  - □ Reason to Exclude: _____

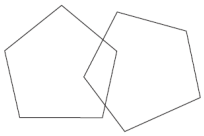
- Tympanometry
  - □ Within Normal Limits
  - □ Reason to Exclude: _____

- Pure Tone Audiometry
  - Air Conduction
    - □ Within Normal Limits
    - □ Reason to Exclude: _____
  - Bone Conduction
    - □ Within Normal Limits
    - □ Reason to Exclude: _____

- Auditory Processing Tests
  - □ Frequency Pattern Test
  - □ Competing Sentences Test
  - □ Low-Pass Filtered Speech Test

APPENDIX E:
MINI-MENTAL STATE EXAMINATION

STANDARDIZED MINI-MENTAL STATE EXAMINATION (SMMSE)

	QUESTION	TIME ALLOWED	SCORE
1	a. ***What year is this?***	10 seconds	/1
	b. ***Which season is this?***	10 seconds	/1
	c. ***What month is this?***	10 seconds	/1
	d. ***What is today's date?***	10 seconds	/1
	e. ***What day of the week is this?***	10 seconds	/1
2	a. ***What country are we in?***	10 seconds	/1
	b. ***What province are we in?***	10 seconds	/1
	c. ***What city/town are we in?***	10 seconds	/1
	d. ***IN HOME – What is the street address of this house?*** ***IN FACILITY – What is the name of this building?***	10 seconds	/1
	e. ***IN HOME – What room are we in? IN FACILITY – What floor are we on?***	10 seconds	/1
3	**SAY:** ***I am going to name three objects. When I am finished, I want you to repeat them. Remember what they are because I am going to ask you to name them again in a few minutes.*** Say the following words slowly at 1-second intervals - **ball/ car/ man**	20 seconds	/3
4	***Spell the word WORLD. Now spell it backwards.***	30 seconds	/5
5	***Now what were the three objects I asked you to remember?***	10 seconds	/3
6	**SHOW** wristwatch. **ASK:** ***What is this called?***	10 seconds	/1
7	**SHOW** pencil. **ASK**: ***What is this called?***	10 seconds	/1
8	**SAY:** ***I would like you to repeat this phrase after me: No ifs, ands or buts.***	10 seconds	/1
9	**SAY:** ***Read the words on the page and then do what it says.*** Then hand the person the sheet with CLOSE YOUR EYES on it. If the subject reads and does not close their eyes, repeat up to three times. Score only if subject closes eyes	10 seconds	/1
10	**HAND** the person a pencil and paper. **SAY:** ***Write any complete sentence on that piece of paper.*** (Note: The sentence must make sense. Ignore spelling errors)	30 seconds	/1
11	**PLACE** design, eraser and pencil in front of the person. **SAY**: ***Copy this design please.***  Allow multiple tries. Wait until person is finished and hands it back. Score only for correctly copied diagram with a 4-sided figure between two 5-sided figures.	1 minute	/1
12	**ASK** the person if he is right or left-handed. Take a piece of paper and hold it up in front of the person. **SAY**: ***Take this paper in your right/left hand*** (whichever is non-dominant), ***fold the paper in half once with both hands and put the paper down on the floor*** . Score 1 point for each instruction executed correctly. Takes paper correctly in hand Folds it in half Puts it on the floor	30 seconds	/1 /1 /1
	TOTAL TEST SCORE		**/30**

Note: This tool is provided for use in British Columbia with permission by Dr. William Molloy. This questionnaire should not be further modified or reproduced without the written consent of Dr. D. William Molloy.

Provided by the Alzheimer's Drug Therapy Initiative for physician use.

APPENDIX F:
FREQUENCY PATTERN TEST SCORE SHEETS

FPT - PARTICPANT # EAR: RIGHT/LEFT SEX: M/F DATE:

Test Items	**Attempt 1**	**Attempt 2**
1. HHL (0:00)	1.	1.
2. HLL (0:08)	2.	2.
3. LHL (0:16)	3.	3.
4. LHH (0:24)	4.	4.
5. LHH (0:32)	5.	5.
6. LLH (0:40)	6.	6.
7. LLH (0:48)	7.	7.
8. HLH (0:56)	8.	8.
9. HHL (1:04)	9.	9.
10. LHH (1:12)	10.	10.
11. HLL (1:20)	11.	11.
12. LHL (1:28)	12.	12.
13. HHL (1:36)	13.	13.
14. HHL (1:44)	14.	14.
15. HLH (1:52)	15.	15.
16. LHL (2:00)	16.	16.
17. LHH (2:08)	17.	17.
18. LLH (2:16)	18.	18.
19. HLH (2:24)	19.	19.
20. LLH (2:32)	20.	20.
21. HLH (2:40)	21.	21.
22. LLH (2:48)	22.	22.
23. HHL (2:56)	23.	23.
24. HLH (3:04)	24.	24.
25. HHL (3:12)	25.	25.
26. HLH (3:20)	26.	26.
27. HLH (3:28)	27.	27.
28. LHL (3:36)	28.	28.
29. LHH (3:44)	29.	29.
30. HHL (3:52)	30.	30.

FPT - PARTICPANT # EAR: RIGHT/LEFT SEX: M/F DATE:

Test Items	Attempt 1	Attempt 2
1. HHL (8:04)	1.	1.
2. HLH (8:12)	2.	2.
3. LLH (8:20)	3.	3.
4. HLL (8:20)	4.	4.
5. LLH (8:36)	5.	5.
6. HLL (8:44)	6.	6.
7. LHL (8:52)	7.	7.
8. HHL (9:00)	8.	8.
9. HLL (9:08)	9.	9.
10. LHH (9:16)	10.	10.
11. HLH (9:24)	11.	11.
12. LHL (9:32)	12.	12.
13. LHH (9:40)	13.	13.
14. HHL (9:48)	14.	14.
15. HLH (9:56)	15.	15.
16. LLH (10:04)	16.	16.
17. HLH (10:12)	17.	17.
18. LHH (10:20)	18.	18.
19. LLH (10:28)	19.	19.
20. HLH (10:36)	20.	20.
21. LLH (10:44)	21.	21.
22. HLH (10:52)	22.	22.
23. LHL (11:00)	23.	23.
24. HLL (11:08)	24.	24.
25. HHL (11:16)	25.	25.
26. LHH (11:24)	26.	26.
27. HLL (11:32)	27.	27.
28. LHH (11:40)	28.	28.
29. HHL (11:48)	29.	29.
30. LHL (11:56)	30.	30.

APPENDIX G:
COMPETING SENTENCES TEST SCORE SHEETS

CST - PARTICPANT # EAR: RIGHT/LEFT SEX: M/F DATE:

Test Items	**Attempt 1**	**Attempt 2**
1. (0:06) a. I think we'll have rain today. b. There was frost on the ground.	1.	1.
2. (0:19) a. This watch keeps good time. b. I was late to work today.	2.	2.
3. (0:30) a. I'm expecting a phone call. b. Please answer the doorbell.	3.	3.
4. (0:41) a. The bus leaves in five minutes. b. It is four blocks to the library.	4.	4.
5. (0:54) a. My mother is a good cook. b. Your brother is a tall boy.	5.	5.
6. (1:04) a. Please pass the salt and pepper. b. The roast beef is very good.	6.	6.
7. (1:16) a. There is a car behind us. b. This road is very slippery.	7.	7.
8. (1:30) a. Leave the keys in the car. b. Fill the tank with gas.	8.	8.
9. (1:42) a. It's always hot on the 4th of July. b. Christmas will be here very soon.	9.	9.
10. (1:52) a. We had to repair the car. b. You should really take a taxi.	10.	10.

CST - PARTICPANT # EAR: RIGHT/LEFT SEX: M/F DATE:

Test Items	**Attempt 1**	**Attempt 2**
1. (2:06) a. The ice cream sundae is very good. b. We have chocolate & strawberry today.	1.	1.
2. (2:19) a. Fasten your seatbelt. b. Get ready for take-off.	2.	2.
3. (2:32) a. I think you need a band-aid. b. You should see a doctor.	3.	3.
4. (2:48) a. This is the latest style. b. That fits you perfectly.	4.	4.
5. (3:02) a. I will be back after lunch. b. You may take this Saturday off.	5.	5.
6. (3:15) a. I have seen this movie before. b. This movie is not like the book.	6.	6.
7. (3:28) a. Air-mail will get there faster. b. Please answer on a postcard.	7.	7.
8. (3:41) a. I think we have met before. b. You probably don't remember me.	8.	8.
9. (3:54) a. This train is going west. b. All the cars are air-conditioned.	9.	9.
10. (4:08) a. The children are playing baseball. b. Football is an exciting game.	10.	10.

APPENDIX H:
LOW-PASS FILTERED SPEECH TEST SCORE SHEETS

LPFS - PARTICPANT # EAR: RIGHT/LEFT SEX: M/F DATE:

Test Items-List 1	**Attempt 1**	**Attempt 2**
1. Home (0:09)	1.	1.
2. Root (0:12.5)	2.	2.
3. Hide (0:16)	3.	3.
4. More (0:21)	4.	4.
5. Lap (0:26.5)	5.	5.
6. Phone (0:29.5)	6.	6.
7. Pole (0:35)	7.	7.
8. Mine (0:39.5)	8.	8.
9. Burn (0:43.5)	9.	9.
10. Ride (0:48)	10.	10.
11. Jar (0:52)	11.	11.
12. Much (0:55.5)	12.	12.
13. Kid (0:59.5)	13.	13.
14. War (1:03.5)	14.	14.
15. Have (1:08)	15.	15.
16. Rain (1:13)	16.	16.
17. Curve (1:18)	17.	17.
18. Patch (1:23)	18.	18.
19. Moon (1:28)	19.	19.
20. Car (1:32.5)	20.	20.
21. Head (1:37.5)	21.	21.
22. Write (1:42.5)	22.	22.
23. Hire (1:48)	23.	23.
24. Gone (1:53)	24.	24.
25. Dumb (1:58)	25.	25.
26. Book (2:03)	26.	26.
27. Toad (2:08.5)	27.	27.
28. Choose (2:13)	28.	28.
29. Shock (2:18)	29.	29.
30. Such (2:23.5)	30.	30.
31. Bite (2:28)	31.	31.
32. Lot (2:33)	32.	32.
33. Dime (2:38)	33.	33.
34. Talk (2:43)	34.	34.
35. Coat (2:48)	35.	35.
36. Shine (2:53)	36.	36.
37. Bone (2:58)	37.	37.
38. Hot (3:03)	38.	38.
39. Search (3:08)	39.	39.
40. Lash (3:13)	40.	40.
41. Coin (3:18)	41.	41.
42. Lag (3:23)	42.	42.
43. Tire (3:28.5)	43.	43.
44. Cash (3:33)	44.	44.
45. Luck (3:37.5)	45.	45.
46. Map (3:42)	46.	46.
47. Neck (3:47)	47.	47.
48. Watch (3:52.5)	48.	48.
49. Fine (3:57.5)	49.	49.
50. Wash (4:03)	50.	50.

LPFS - PARTICPANT # EAR: RIGHT/LEFT SEX: M/F DATE:

Test Items-List 2	**Attempt 1**	**Attempt 2**
1. Wood (0:8.5)	1.	1.
2. Hash (0:13)	2.	2.
3. Dad (0:17.5)	3.	3.
4. Work (0:22.5)	4.	4.
5. Chum (0:27.5)	5.	5.
6. Hush (0:32.5)	6.	6.
7. Hate (0:37)	7.	7.
8. Which (0:42)	8.	8.
9. Joke (0:47)	9.	9.
10. Limb (0:52)	10.	10.
11. Weak (0:57)	11.	11.
12. Mire (1:02.5)	12.	12.
13. Loop (1:07.5)	13.	13.
14. Jet (1:11.5)	14.	14.
15. What (1:16.5)	15.	15.
16. Chin (1:22)	16.	16.
17. Job (1:27)	17.	17.
18. Turn (1:32)	18.	18.
19. Move (1:37)	19.	19.
20. Word (1:41)	20.	20.
21. Wash (1:46.5)	21.	21.
22. Vine (1:51)	22.	22.
23. Love (1:56)	23.	23.
24. Bar (2:00.5)	24.	24.
25. Juice (2:05.5)	25.	25.
26. Doc (2:10)	26.	26.
27. Hole (2:16)	27.	27.
28. Wheat (2:21)	28.	28.
29. Shade (2:27)	29.	29.
30. Neat (2:31.5)	30.	30.
31. Wish (2:36.5)	31.	31.
32. Pan (2:41.5)	32.	32.
33. Room (2:46.5)	33.	33.
34. Tone (2:52)	34.	34.
35. Bug (2:57)	35.	35.
36. Tube (3:02)	36.	36.
37. Bun (3:07)	37.	37.
38. White (3:11.5)	38.	38.
39. Pile (3:16.5)	39.	39.
40. Nose (3:21.5)	40.	40.
41. Should (3:27)	41.	41.
42. Loan (3:31.5)	42.	42.
43. Light (3:36)	43.	43.
44. Wire (3:40.5)	44.	44.
45. Sure (3:45.5)	45.	45.
46. Wet (3:51)	46.	46.
47. Dish (3:56)	47.	47.
48. Hair (4:01.5)	48.	48.
49. Well (4:06)	49.	49.
50. Pull (4:10.5)	50.	50.

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