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Auditory processing skills in normal hearing adult listeners with and without self-reported auditory skill complaint

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Auditory Processing Skills in Normal Hearing Adult Listeners with and without Self-Reported Auditory Skill Complaint

by

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Abstract: Auditory Processing Tests, including the PPST, the DDT, the HINT, and the RGDT, were administered to normal hearing adults between the ages of 20-40. No differences were indicated between results of the Control and Experimental groups, though differences within the Experimental group were noted on the DDT, the HINT, and the RGDT.

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Tables and Figures

Abbreviations

ABR	Auditory Brainstem Response
ADHD	Attention Deficit Hyperactivity Disorder
AMLR	Auditory Middle Latency Response
ANOVA	Analysis of Variance
ANSI	American National Standards Institute
APD	Auditory Processing Disorder
ASHA	American Speech-Language Hearing Association
ASQ	Auditory Skills Questionnaire
BKB	Bamford Kowell Bench Sentences
CANS	Central Auditory Nervous System
CNS	Central Nervous System
dB	Decibels
DDT	Dichotic Digits Test
FM	Frequency Modulated
GSI	Grason Stadler Instrument
HINT	Hearing in Noise Test
HL	Hearing Level
HRPO	Human Resource Protection Office
Hz	Hertz
PACS	Program in Audiology and Communication Sciences
PI	Primary Investigator

PPST	Pitch Pattern Sequencing Test
RGDT	Random Gap Detection Test
RTS (dB)	Reception Threshold for Sentences in dB
SRT	Speech Recognition Threshold
TBI	Traumatic Brain Injury

Introduction

Identification and treatment of patients with auditory processing disorder (APD) has gained prominence within the field of audiology throughout the preceding decades (Sahli, 2009). Dating back to 1954 when Myklebust suggested that some children may experience difficulties with auditory perception while exhibiting normal hearing and normal cognitive function, most research and clinical work has focused less on the adult population and more on school aged children (p. 155-156). While APD has been designated a low incidence disorder, the population has been identified as heterogeneous. Referred children are known to exhibit symptoms such as: inattentiveness, difficulty understanding and/or processing auditory messages in noise, difficulty carrying-out spoken directions, requesting repetition often, and others (Bamiou, Musiek, & Luxon, 2001; Daws, Bishop, Sirimanna, & Bamiou, 2008; Whitelaw, 2008; Yalçinkaya, Muluk, & Şahin, 2009).

Due to the characteristic symptomology of APD, differential diagnosis may be complicated when using purely behavioral assessment tools. Disorders with the same or similar behavioral characteristics include: "attention deficit hyperactivity disorder (ADHD), language impairment, reading disability, learning disability, autism spectrum disorders, and reduced intellectual functioning" (Jerger & Musiek, 2000, p. 468). Moore (2006) reported "auditory neuropathy" as an additional disorder that presents with APD-like symptomology (p. 5). Further, in individuals where APD has manifested, concomitant language impairments; behavioral, neurologic, and/or neural disorders; genetic disparities; and other disorders may also be present, making the APD diagnosis arduous (Dawes, Bishop, Dirimanna, & Bamiou, 2008; Moore, 2006; Rosen, 2005; Sahli, 2009).

Because of the possible involvement of other concomitant disorders or possible misdiagnosis due to the symptomology of APD and other similar disorders, it has been suggested by many clinicians and researchers that the diagnosis of APD be assessed using multi-professional collaboration (American Speech-Language and Hearing Association, 2005; Bellis & Beck, 2000; Medwetsky, 2006; Musiek, Baran, Shinn, Guenette, Zaidan & Weihing, 2007). The audiologist's role clinically is the actual diagnosis of APD, but others who may be a part of the process include professionals such as speech language pathologists, psychologists, educators, occupational therapists, parents, and others (American Academy of Audiology, 2010; American Speech-Language Hearing Association, 2005; Sahli, 2009). These professionals aid in the differential diagnosis process by ensuring that all factors such as "attention, auditory neuropathy, fatigue, hearing sensitivity, intellectual and developmental age, medications, motivation, motor skills, native language, language experience, language age, response strategies and decision-making style, and visual acuity" have been considered (Jerger & Musiek, 2000, p. 470).

During the diagnosis process, tests chosen and administered by the audiologist have been specifically designed to identify an auditory processing disorder. Falling under the umbrella of auditory processing tests lie two testing categories: behavioral tests and electrophysiologic tests. Behavioral measures explore performance on an array of auditory skills while taxing the auditory system and/or degrading the signal. Subcategories of auditory processing tests exist within both of these categories. Within the division of behavioral testing, the subcategories of APD assessments include, but are not limited to: tests of temporal resolution, tests designed to tax the right and left auditory pathways using dichotic stimuli, tests of auditory closure abilities, and those that assess spatial recognition abilities (American Academy of Audiology, 2010). Within the electrocphysiologic assessments for APD, the subcategories are: Auditory Brainstem

Response testing (ABR), Auditory Middle Latency Response testing (AMLR), and the P300 late evoked response (American Academy of Audiology, 2010; Bellis & Beck, 2000; Jerger & Musiek, 2000).

If a diagnosis of APD is warranted following the APD assessment and convening of a multidisciplinary team, treatment of the disorder may involve certain remediation strategies, such as environmental modifications, or even therapy. Depending upon the weakness identified during APD assessment, environmental modifications like noise reduction and seating within close proximity to the speaker and away from the noise source may be necessary in the classroom or office setting. The individual may benefit from written instructions, repetition of the speaker, and memory strategies, like “chunking and mnemonics” which help the individual group bits of information together in order to enhance his/her recall abilities (Sahli, 2009, p. 111-112). An FM personal amplification device may also be beneficial (American Academy of Audiology, 2010). Additionally, auditory training for management of APD includes strategies like “FastForWord,” “Earobics,” and “vowel/consonant training” (Bamiou, Musiek, Luxon, 2001, p. 364). Therapy strategies are appropriate when warranted. For example, a speech-language pathologist may provide speech and language services or aural rehabilitation may be received from an audiologist (American Academy of Audiology, 2010).

Any treatment(s) applied should be specific to the affected individual, targeting areas in which the APD exists and with which the patient is struggling (American Academy of Audiology, 2010; Bellis & Beck, 2000). According to Moore (2006), remediation which is focused on the specific abilities impacted by the APD has been shown to be more effective than a remediation approach which is more broadly focused. When developing an APD treatment plan, the clinician should consider identifying the component of APD with which the patient struggles according to outcomes of the APD test battery; difficulties subjectively reported by the patient, family members, or caregivers; and corresponding findings pertaining to speech and language difficulties (American Speech-Language Hearing Association, 2005; Bellis & Beck, 2000; Moore, 2006). Further, Medwetsky (2006) suggested that the patient will benefit most from APD treatment strategies if they are applied in a variety of the patient's environmental settings.

The APD treatment strategies mentioned above have been cited while keeping both children and adults in mind. Commonly, APD research in the adult population involves the aging population, adults who have suffered from traumatic brain injuries (TBI), and/or those who are dyslexic. In the aging population, changes in hearing or auditory skills have been attributed to age-related anatomical structural changes throughout the auditory system, including the "cochlea, eighth nerve, [and the] Central Auditory Nervous System (CANS)" (Marshall, 1981, p. 226). These changes compromise auditory skills, contributing to decreased abilities of the older patient when comprehending and remembering auditory messages (Kricos, 2006). The difficulty lies in differentiating effects of age-related hearing loss versus auditory processing difficulties related to impairment of the CANS and cognition factors (Kricos, 2006; Marshall, 1981).

Further research has shown that in adults who experience head injuries, especially in cases of TBI, insult may have occurred to areas of the brain that support auditory function. If this occurs, auditory processing complaints like difficulty maintaining attention in the presence of background distractions may arise, though pure tone thresholds remain stable (Musiek, Baran, Shinn, 2004). Another group of adults closely associated with auditory processing difficulties is dyslexic adults or those reporting reading difficulties. As defined by Hari and Kiesilä (1996), "Developmental dyslexia is a specific disability in learning to read despite conventional instruction, adequate intelligence and opportunity" (p. 138). These researchers demonstrated that dyslexic adults tended to express difficulty with temporal auditory processing tasks (Hari & Kiesilä, 1996).

Outside of the pediatric population and the adult population discussed above, there is a paucity of research addressing the young adult population who experience auditory skill complaint although they have normal hearing sensitivity and normal cognition. It is common knowledge among audiologists that a diagnosis of APD is generally made around the age of seven. The possibility exists that adults exhibit the same auditory skill complaints, yet are under diagnosed because their age surpasses the typical age of diagnosis. According to Medwetsky (2006), the emergence of APD began with researchers investigating auditory skill complaint and site of lesion in both the adult and pediatric populations. Soon after, research began to focus on those within the educational setting, assessing general success or performance in this population. It has been suggested that children are more often suspected of having APD, meaning that children receive more referrals for APD testing from educators and caretakers than adults, who might assume their difficulty is related to hearing loss (Bellis & Beck, 2000. Further, the lack of research regarding APD in young adults might be due to a lack of interest. For example, Moore (2006) stated that both adults and children may be diagnosed with APD; yet his research was conducted solely within the pediatric population (p. 4).

Auditory Processing Disorder has been defined by the American Speech-Language Hearing Association (ASHA) as:

> difficulties in the processing of auditory information in the central nervous system (CNS) as demonstrated by poor performance in one or more of he following skills: sound localization and lateralization; auditory discrimination; auditory pattern recognition;

> temporal aspects of audition, including temporal integration, temporal discrimination (e.g. temporal gap detection), temporal ordering, and temporal masking; auditory performance in competing acoustic signals (including dichotic listening); and auditory performance with degraded acoustic signals (2005, para 4).

In a 2009 study conducted by Yalçinkaya, Muluk, and Şahin, the impact of auditory reception capabilities on speaking, writing, and reading skills was examined in students approximately six to eight years of age with normal cognition and no history of hearing loss. They were assigned to one of two study groups: those at risk for APD and those not at risk for APD. Results of the study indicated that significant differences were present between the two groups. Children in the APD group tended to show increased difficulty in listening tasks, speaking tasks, reading tasks, and writing tasks than did children in the normal, or "control," group. Those in the control group showed a statistically significant, positive relationship between listening and speaking skills and reading and writing capabilities. For children in the experimental APD group, a positive correlation was present between "listening and writing," "speaking and writing," and "reading and writing" capacities (p. 1140).

Kreisman, John, Kreisman, Hall, and Crandell (2012) studied children with APD and the psychosocial impact of the disorder. There were 39 participants between 10 and 19 years of age. Inclusion criteria stated that all participants have hearing abilities within normal limits, normal tympanometric results, normal or greater cognitive ability, and no diagnosis of attention disorders. A battery of six APD tests was administered in order to determine whether they were to participate in the control (non- APD) group or experimental (APD) group. Once these groups were determined, all subjects were given questionnaires related to intrapersonal skills, emotional state and overall happiness, and the ability to acclimate to change. Their caregivers were given assessment forms asking for their subjective observations of the participants' psychosocial behaviors. Findings from this study revealed that participants in the experimental group were more likely to experience general wellness and emotional distress more profoundly than someone in the non-APD control group. Further, caregivers of those in the APD group reported psychosocial difficulties more than those of the non-APD participants.

There are many ways to assess the impact of APD upon the affected individual. A battery of tests is chosen and then administered by the audiologist. Behavioral aspects of APD can be explored and quantified by using behavioral tests, while neurological impact might be assessed by electrophysiologic measures. There are no specific guidelines dictating what assessments must be part of the APD battery. Instead, the audiologist should choose the APD test method according to what is most appropriate for the patient, and the challenges experienced (Bellis, 1996).

Many audiologists do feel that a **battery** of tests is crucial for implementation. Each test will likely evaluate various and differing auditory skills and various levels of the CANS. In addition, a combination of linguistically- and non-linguistically loaded measures may be utilized. The tests used must be normed and appropriate for the patient's age.

One very common complaint of APD is difficulty hearing in the presence of noise (American Academy of Audiology, 2010). A number of tests have been used to assess this complaint, yet most were limited by floor and ceiling effects (Nilsson, Soli, Sullivan, 1993). To avoid the floor and ceiling effect, the Hearing in Noise Test (HINT) was developed. Bamford Kowel Bench (BKB) sentences were adapted for use by native American English speakers, instead of the original British version of the sentences. Sentences were recorded using a male talker at "70 dB SPL." Testing is conducted in two conditions: first, the stimuli is presented in quiet, then noise is introduced at adaptive "spectrally matched" levels while the participant attempts to hear and understand the speech stimuli (p. 1086-1088). The HINT is an example of a monaural low- redundancy speech perception test, as its purpose is to assess understanding ability with and without the presence of noise (American Academy of Audiology, 2010; Nilsson, Soli, Sullivan, 1993).

The Random Gap Detection Test (RGDT) is another commonly utilized test in the APD battery. It is strictly a test of temporal processing and examines how acoustic stimuli are processed over time. This test should be chosen as part of the diagnostic test battery if the patient experiences difficulty understanding rapid speech or if he/she presents with a delay in speech or language (Muluk, Yalçinkaya, Keith, 2011). In a study by Dias, Jutras, Acrani, and Pereira (2012), it was concluded that individuals with APD were likely to exhibit poor RGDT performance (p. 177). Keith (2003) explained that the basic components of testing include presenting two stimuli with a silent gap that is present between the stimuli presentations. The gap detection threshold is found when the two stimuli are just far enough apart for the gap and two stimuli to be identified. If the gap is not identified, one sound will be heard instead of two. The more time it takes between the two stimuli for the patient to detect the gap, the more inclined the patient is to present with an APD (para. 1).

The Pitch Pattern Sequence Test (PPST) is a test of auditory discrimination. The underlying characteristics of auditory discrimination include frequency, intensity, and duration. The ability to process temporal, or timing, cues is imperative when developing speech understanding and/or perception skills, language skills, and reading skills (American Academy of Audiology, 2010; Baran, 1996; Bellis; 1996; Musiek, 1994). In 1987, Musiek and Pinheiro stated that frequency pattern testing was minimally affected by "cochlear" hearing loss, though it was found to be a reliable identifier of individuals with cerebellar lesions (p. 82-83).

The PPST was developed to tax a patient's temporal abilities using assessments of temporal ordering and frequency recognition (Bellis, 1996). A slightly modified version of the original frequency pattern assessment by Pinheiro and Ptacek (1970) is administered today as the PPST. It is a monaural test, with stimuli consisting of 30 pitch pattern sequences presented to both ears. The sequences contain three varying tones that are either high (1,122 Hz) or low frequency (880 Hz) (Baran, 1996). Scoring is based on the percentage of sequences the patient correctly repeats.

Others with APD might report experiencing dominance of one ear over the other ear, noticing difficulty especially in loud situations or with competing speakers. The Dichotic Digit Test (DDT) explores binaural integration capabilities and whether they are functioning or impaired (Guenette, 2006; Musiek, 1994). The test is administered in a dichotic listening condition at 50 dB above the patient's threshold, with two number stimuli presented to each ear. The patient's score is felt to have implications for success with speech and language acquisition and development, as well as success in hearing aid or other amplification device outcomes (Guenette, 2006).

After citing results from the previous child-focused studies, clear implications exist for pursuing further research of auditory processing complaints in the young adult population. Bamiou, Musiek, and Luxon (2001) note that the approximate percent of children affected by APD is seven percent, yet similar statistics are not offered for the adult population (p. 361). As has been mentioned, children are referred more for APD testing than adults who present with the same symptoms (Bellis & Beck, 2000. Yet, psychosocial implications for undiagnosed adults may exist, similar to those present in children with APD as cited by Kreisman, John, Kreisman, Hall, and Crandell (2012). This general lack of APD research in the young adult population may be attributed to the further lack of research regarding how hearing is affected when the CANS is impaired (Musiek et al., 2004). Musiek points out that subjective reports of patients affected in this way could contribute insights leading to greater research development. Essentially, normative data exist for all populations undergoing APD testing, including adults. Yet children and specific adult populations seem to be a target of greater focus than the young adult population.

Aims of this study

Two groups of young adults were recruited for this study. Members of the Control group reported two or less challenges in difficult listening situations, while the Experimental group members reported three or more. Such self-reports were elicited by the principal investigator (PI) prior to each testing session. Aims of the current study included:

1. Determination of specific challenges that the Experimental group subjects noted in difficult listening situations.

2. Construction of an APD test battery that may be effectively and efficiently utilized clinically with this population.

3. Exploration of test sensitivity and specificity were explored.

4. Development of suggestions for remediation, based upon findings of the implemented APD test battery.

The primary research hypothesis of this study follows that subjects within the Experimental group would perform significantly poorer on tests comprising the APD battery than subjects within the Control group. The four behavioral tests comprising the APD battery were the HINT, the RGDT, PPST, and DDT.

Methods and Materials

Participants

Twenty-four participants were recruited for this study following approval by the Washington University School of Medicine Human Research Protection Office (HRPO). Table 1 lists participant demographics. Of the participants, three were male and 21 were female. Of the 24 total participants, 22 fell within the 20-30 year age range, while two of the participants were 31-40 years of age. The participants' cumulative mean age was 25.04 years with a standard deviation of +/- 4.38 years.

To determine the number of participants needed for this study, a power analysis utilizing G-Power 3 software was performed. The investigators implemented sample mean data from similar studies appearing in the professional literature, two-tailed testing with $p<.05$ and power value = .8.

Inclusion Criteria required that participants be at least 20 years of age and no greater than 40 years of age with normal hearing sensitivity. Subjects were recruited into two groups: those reporting and those denying the experiencing of auditory processing complaints. Examples of such complaints included frequently requesting repetition, difficulty understanding subtle meanings within social conversations, being easily distracted by background noise, and others. The stipulated age range was determined for Inclusion Criteria in order to recruit adult subjects while ruling out potential effects of presbycusis. Also, normal hearing sensitivity was required so that any difficulty seen on the auditory processing portion of the test session could not be attributed to peripheral hearing loss. Exclusion Criteria included those older or younger than the specified age, those with a hearing loss, as well as those with abnormal tympanometry results. Exclusion Criteria also included history of known neurologic and/or otologic disease.

Participants were recruited from the Washington University in St. Louis School of Medicine Division of Adult Audiology, AudBase, in addition to HRPO-approved recruitment flyers posted throughout Washington University in St. Louis School of Medicine and other area locales. All testing was completed in one test session, which took place within the Program in Audiology and Communication Sciences (PACS) Student Lab located in the Harold Siebens Hearing Research Building. Participants were not given compensation for participation in the study. Each study session began with the Principal Investigator's (PI) attainment of the participant's informed consent.

Determining Control vs. Experimental Group

Of the twenty-four total participants, twelve were designated to the Control group with the other twelve participants belonging to the Experimental group. The Control group was devised to consist of subjects who demonstrated little or no auditory complaints in everyday listening situations. The Experimental group was devised to consist of subjects who reported three or more auditory skill complaints. Assignment to the Control or Experimental group was determined by administering an Auditory Skills Questionnaire (ASQ) to each participant at the beginning of the testing session (Appendix). The questionnaire consisted of 18 questions, 15 of which required "Yes" or "No" answers. Seven questions were used to determine inclusion or exclusion within the study, while the other 11 were used to determine whether the participant belonged in the Control or Experimental group. Of these 11 questions, if the participants answered "Yes" on two or less, he/she was included in the Control group. If three or more questions received a "Yes" answer, he/she was included in the Experimental group. The questionnaire was devised by the PI and her Advisor based on common complaints routinely reported to audiologists in clinical practice. Some questions were also adapted from the "APD:

Behaviors of At Risk Children" questionnaire with permission from the Center for Hearing and Speech in St. Louis, Missouri.

Equipment

Following administration of the questionnaire, the research test protocol was administered to each subject. This protocol consisted of an initial hearing screening to further ensure that Inclusion Criteria were being met, as well as administration of four auditory processing tests. During the initial evaluation procedures, the GSI 33 Middle-Ear Analyzer and the GSI 61 Clinical Audiometer were utilized. The GSI 33 Middle-Ear Analyzer was used to obtain tympanometric results by utilizing a 226- Hz probe tone via standard clinical practice. The GSI 61 Clinical Audiometer was used to obtain air conduction thresholds at 500, 1,000, 2,000, and 4,000 Hz. Telephonics TDH-50P circumaural headphones- model 296D200-2 were coupled to the audiometer and utilized for pure-tone screening procedures. Diagnostic audiometer calibration was carried out prior to beginning the study, in order to assure that all was functioning according to ANSI Standards and Specifications. In addition, all measures were obtained in a single-walled sound booth located within the acoustically-treated laboratory room.

Speech Recognition Thresholds (SRTs) were also obtained for each participant, the procedure of which is described below. The GSI 61 Clinical Audiometer and accompanying transducers that were previously described were utilized for obtaining of SRTs.

When administering the AP battery of tests, including the HINT, the DDT, the RGDT, and PPST, the GSI 61 Clinical Audiometer was again used and was accompanied by the SONY Compact Disc Player CDP-591, a GSI speaker designated as the left speaker located in the sound booth, and Telephonics TDH-50P circumaural headphones- model 296D200-2. The following compact discs were played during AP testing: the Dichotic Digits disc for administration of the Dichotic Digits Test, the Department of Veteran's Affairs disc for administration of the Frequency (Pitch) Perception Sequencing Test, and the AUDiTEC of St. Louis disc for administration of the HINT and the Random Gap Detection Test. Calibration of the GSI 61 Clinical Audiometer (via a 1,000 Hz calibration tone) took place for each of the compact discs before each AP test began.

Screening Procedure

To insure that participants fell within the Inclusion Criteria, screening measures took place. First, participants underwent an otoscopic examination noting presence or absence of cerumen, debris, or other anomalies that could have affected results of the study. Next, tympanometry was performed using a 226-Hz probe tone to help determine normal or abnormal middle ear function by assessing static admittance, middle ear pressure, and ear canal volume. Pure-tone air conduction thresholds were found at 500, 1,000, 2,000, and 4,000 Hz, followed by finding the participant's SRT, bilaterally. Hearing thresholds and SRT findings of ≤20 dB HL was considered within normal limits. Determination of the SRT allowed the PI to determine appropriate presentation level for the auditory processing testing portion of the session.

Experimental Protocol: Auditory Processing Testing

Following performance of the screening procedures, four auditory processing tests were administered, and included the HINT, RGDT, PPST, and DDT. During testing, participants were seated within a sound-treated audiometric test booth at 0 degrees azimuth relative to the left soundfield speaker. Circumaural headphones were worn by the participant during administration of air-conduction stimuli, SRTs, and three of the auditory processing tests including the RGDT, PPST, and DDT. Administration of the four tests was counterbalanced. With tests that involved monaural tasks, counterbalancing between right and left ears was also performed.

Hearing in Noise Test (HINT)

The HINT was developed so that clinicians might predict the reception threshold for sentences (RTS) in dB with which listeners could repeat a sentence 50 percent of the time, though competing noise was present. Essentially, this test serves to help determine how well the subject understands speech stimuli when background noise is present. Within the sound-booth, subjects were seated one meter away from the left speaker, at a 0 degree angle. After calibrating External A on the GSI 61 audiometer, speech-weighted noise and sentence stimuli were presented simultaneously from the left speaker to the subject.

As the HINT instruction manual specified using a 65 dB A speech-weighted noise signal, a handheld Quest Sound Level Meter model #215 was used to convert the stimuli to dB HL. This was done at a distance of one meter from the left speaker while sentences were being presented. Sound level measures were taken with use of a 1-inch microphone coupled to the Sound Level Meter OB-45 Octave Band Filter. Calibration of the Sound Level Meter and accompanying system as described was checked via usage of a 12 B calibrating Pistonphone. Through calibration in this manner, the corresponding level of the speech noise was found to be 50 dB HL; therefore the speech-weighted noise was presented at this constant level while sentence stimuli were presented simultaneously to the participant using an adaptive method.

This adaptive method called for sentences to first be presented four dB lower than the noise level. The first sentence was presented repeatedly until the subject said it correctly, followed by a four dB increase for each consecutive presentation. The presentation level for the second sentence was lowered four decibels, and depending on a correct or incorrect answer, the presentation level was increased (incorrect response) or decreased (correct response) by four decibels for sentences three and four. Sentences 5-20 were presented using an adaptive step level of two dB. For the purposes of this study, two lists of 10 sentences were used and combined to form one list of 20 sentences. Scoring was recorded as the participant's RTS in dB.

Random Gap Detection Test

The RGDT has been noted as an integral part of many auditory processing test batteries, due to its ability to assess temporal processing abilities. As a diotic task, participants wear earphones to listen to the same stimuli simultaneously with both right and left ears. Presentation stimuli consist of two tones with a gap of differing durations embedded in the middle of the presentation at 500, 1,000, 2,000, and 4,000 Hz. Gap durations include 0, 2, 5, 10, 15, 20, 25, 30, and 40 milliseconds. Stimuli were presented at 55 dB HL re: the participants' SRT. The subject was to indicate after each presentation whether he/she heard one or two tones. One tone may be perceived if a shorter duration gap is present between the tones, and two tones may be perceived if there is a longer duration gap. In the current study, the purpose of this test was to determine the shortest duration gap where the subject heard two stimuli as opposed to just one, therefore testing binaural integration capabilities. Scoring for each subject involves reporting the shortest duration gap, or random gap detection threshold, across the stimulus frequencies.

Pitch Pattern Sequencing (PPST)

The PPST is a test of temporal sequencing and was administered to participants to determine their ability to perceive differences in high versus low frequency stimuli. Participants were administered the test material monaurally via circumaural earphones. Stimuli consisted of a series of three tones, each tone being of either high (1,122 Hz) or low (880 Hz) frequency (Baran, 1996). Following the presentation of three tones, the participant was instructed to identify each of the tones as being "high" or "low." An example sequence would be "low pitched tone, high pitched tone, high pitched tone" in one presentation, and the participant would answer “low, high, high.” Measures obtained following testing involved a percentage of correct responses in each ear.

Dichotic Digits Testing (DDT)

Clinicians have routinely used the DDT due to its adroitness in identifying an APD. Specifically, this task assists in determining the participant’s ability to separate differing signals arriving simultaneously at the two ears. Therefore, this test is a dichotic task, meaning that participants listened via earphones to differing stimuli at each ear though they were presented simultaneously. With each test item, the subject heard two digits presented to the right ear and two differing digits presented to the left ear. The participant then repeated all four of the digits he/she had heard. Stimuli consisted of digits one through 10, though the number seven was excluded from stimuli per the original test protocol. Measures obtained following testing involved a percentage correct out of possible 100%.

Although scoring was performed following each test session and no results were imparted to subjects, they were generally counseled regarding optimizing listening skills in challenging listening situations. This took place if the subject requested basic information.

Results

Statistical Analyses

Due to the fact that data were not normally distributed in either sample (Control or Experimental group), the following measures were utilized to describe distribution values for each APD test performed: Median, Minimum, and Maximum Values (or Range from Minimum to Maximum). Because underlying assumptions of parametric statistical procedures were not met, the Mann Whitney U Test was performed. This non-parametric significance test is a rank-summed measure that is commonly implemented for comparison of independent samples. Specifically, it assists the examiner in determining whether there are significant differences between data collected from one sample (Control group) and the other (Experimental group). A major underlying assumption of the Mann Whitney U Test is that sample distributions are homogeneous.

As previously stated, the Mann Whitney U Test was utilized to determine presence of significant differences in performance among groups (Control versus Experimental) on four APD tests: PPT, DDT, HINT, and RGDT. Upon data analysis with regard to the RGDT, the Friedman's Test was utilized to determine whether there were significant differences among distributions of data collected at each frequency (500, 1,000, 2,000, and 4,000 Hz), as a function of group (Control versus Experimental). The Friedman's Test may be viewed as a nonparametric equivalent for Repeated Measures Analysis of Variance (ANOVA). In that significant differences among frequencies were seen for the Experimental Group, the Wilcoxon Test was implemented for post hoc analysis to further determine where significant differences were present. The alpha level was adjusted for the number of comparisons using Bonferroni's correction.

Explanation of Use of Box-Plot Graphs in Figures 2-7

Following data-analysis of the PPST, DDT, HINT, and the RGDT, box-plot graphs were utilized to display statistical results in Figures 2, 3, 4, 5, 6, and 7. Boxes represent middle quartiles of the data distributions from 25% - 75%, with the upper boundary of the box representing that 25% of the data are greater than this value and the lower boundary representing that 25% of the data are less than this value. The darkened line seen within each box represents the median (middle of the dataset) where 50% of the data are greater than this value. The "whiskers" or bars appearing above the boxes represent the greatest or maximum value, while the bars appearing below the boxes represent the least or minimum value. Circular symbols represent outliers. If an outlier appears below the box-plot, it represents a data point that is less than 3/2 times the lower quartile value. If the outlier appears above the box-plot, it represents more than 3/2 times the upper quartile value.

Questionnaire Results

The ASQ was administered to all participants in order to determine inclusion in either the Control or Experimental group. Questions five through 15 list specific auditory processing related complaints. The following questions are examples of questions that were included in the ASQ, which can be viewed in the Appendix: "Are you easily distracted by background noise," "Do you forget names, dates, times and other information that you recently ***heard***," and "Is daydreaming or a lack of attention a common problem for you?" Responding "yes" to a question meant that the individual did experience that specific auditory processing complaint, whereas an answer of "no" indicated that the individual did not experience the auditory processing complaint in question. Questionnaire results of the Experimental and Control groups were compared and are displayed in Figure 1. Results shown in Table 2 demonstrated that the Experimental group reported "yes" more frequently on all questions than did those in the Control group, indicating greater subjective feelings of difficulty with auditory processing skills than what was reported by those in the Control group.

Questions from the ASQ were ranked according to frequency of “Yes” responses from the Experimental group. Of the 11 AP related questions, 10 participants reported “Yes” to the question “Are you easily districted by background noise?”. This was the most popular symptom reported on the ASQ. Eight of the 12 participants stated that daydreaming or a lack of attention was a common problem for them. This was followed in popularity with seven reports of forgetting names, dates, times and other information that had recently been heard. “Do you find that you are unorganized or messy?” received six positive responses. Five participants reported that even though they had normal hearing they felt as though they frequently asked for repetition, in addition to rapid speech being difficult for them to understand, and saying “huh” or “what” a lot. Only four participants reported that they sometimes had difficulty understanding subtle meanings within social conversations or in social gatherings. Both questions “Do you often experience difficulty following spoken directions?” and “Do you ever experience difficulty with spelling and/or reading?” were answered “Yes” by three participants. And finally, the question which received the least “Yes” responses on the ASQ was “Do you have difficulty locating where a sound is coming from?”.

Control group responses on the ASQ did not show as much variability as did responses of the Experimental group. Of interest is the fact that the most reported complaints for the Experimental group were also the most popular complaints for the Control group, although the frequency of “Yes” responses was greatly decreased for these participants in the Control group (Table 2, Figure 1).

Pitch Pattern Sequencing Test

Table 3 displays Pitch Pattern Sequencing Test results for the Control and Experimental groups. The “Group” variable is listed in the first column (Control versus Experimental), as well as number of subjects in each group (N=12 in Control group and N=12 in Experimental group). Median values are listed in the second column for each group, while the Minimum to Maximum range for each group may be viewed in the third column.

Figure 2 displays box-plots obtained following data analysis for this test, which is a monaural measure. In that no significant differences were seen between right and left ears in either group, therefore data obtained for right and left ears were collapsed. The variable of "Group" is displayed along the x-axis, demonstrating data as a function of Control group versus Experimental group. The variable of "Score in Percentage Correct" is shown along the y-axis. There were no statistically significant differences seen between Control and Experimental groups on the Pitch Pattern Sequencing Test (p=0.321), as was demonstrated in the box-plots and via statistical analysis.

Dichotic Digits

As the DDT assesses right and left ears separately, Table 4 displays DDT results of the right ear for both the Control and Experimental groups, as well as results of the left ear for each group. This table was configured to show the "Group" variable (Control versus Experimental) in the first column, ear results in the second column, Median values of both groups in the third column, and Minimum to Maximum group values in the fourth column. These data were not collapsed, in that there was a significant difference seen between the right and left ear for the Experimental group (p=0.046). No significant ear differences were seen for the Control group (p=0.066).

Figures 3 and 4 display the DDT results. Figure 3 displays two box-plots, one for right ear results of the Control group and one for right ear results of the Experimental group. Figure 4 also displays 2 box-plots, this time comparing left ear results of the Control and Experimental groups. The x-axis notes the variance of "Group," either Control or Experimental. The y-axis displays score as a function of percent correct on this particular measure.

These figures, in addition to results of the statistical data, demonstrate that no statistically significant difference was noted between the Control and Experimental groups. The reader is reminded, however, that a significant difference was found to exist at the $p<0.5$ level between results of the left and right ears of those in the Experimental group ($p=0.046$).

Hearing In Noise Test

Please see Table 5, which displays results of the HINT in RTS in dB. Control group versus Experimental group participation is specified in the first column, Median RTS (dB) values are listed in the second column, and Minimum and Maximum RTS in dB values are in the third column.

Figure 5 displays a representation of RTS in dB values for the Control and Experimental groups. The "Group" variable may be noted along the x-axis, while RTS (dB) may be seen along the y-axis. Though it is clearly shown that the Experimental group results had greater variability than results of the Control group, there were no statistically significant differences among Experimental and Control participants at the $p<.05$ level ($p=0.219$).

Random Gap Detection Test

Table 6 displays results of the Control group and Experimental group obtained on the RGDT. The first column identifies "Group" (Control or Experimental). The "Median" measures, were reported in the second column. These were obtained by adding reported gap detection thresholds (in msec.) at 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz for each of the two groups. The third column indicates the Minimum to Maximum range of gap detection thresholds in milliseconds.

Box-plots were used to display results for the binaural task, this is shown in Figure 6. Once again, “Group” affiliation is labeled on the x-axis, while the y-axis dictates “Random Gap Detection,” or the shortest duration in milliseconds when a person detects two signals. This figure demonstrates that there was no statistically significant difference between the Control and Experimental groups ($p=0.109$).

Data were also analyzed to determine if there were significant differences between the two groups at each individual frequency (500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz). Table 7 displays these data, with Frequency in Hz noted in the first column. The second column contains the Median values of the Control group along with the participants’ range of responses in milliseconds. In the third column, the Experimental group’s Median values are listed, and again the range of participant responses in milliseconds follows. The fourth column lists the p-values found by comparing the Control group responses and the Experimental group responses.

Figure 7 contains box-plots that display RGDT as a function of frequency. The “Frequency” variable appears across the x-axis, while the Random Gap Detection Threshold appears along the y-axis. No significant differences were found between groups at any frequency tested ($p = 0.236$ at 500 Hz, $p = 0.214$ at 1,000 Hz, $p = 0.682$ at 2,000 Hz and $p = 0.078$ at 4,000 Hz). However, a statistically significant difference was detected within the Experimental group between the 2,000 Hz and 4,000 Hz conditions ($p=0.034$).

Discussion

The purpose of this Capstone project was to investigate and compare outcomes of the ASQ, the PPST, the DDT, the HINT, and the RGDT of normal hearing young adults who reported difficulty with auditory processing skills (Experimental group) and those who did not report difficulty with auditory processing skills (Control group). It was hypothesized that the Experimental group would answer "Yes" more often to questions on the ASQ than would the Control group. Further, the researchers hypothesized that the Experimental group would score more poorly on all four auditory processing tests utilized for this study than the Control group: the PPST, the DDT, the HINT, and the RGDT.

Results of the ASQ helped to confirm our hypothesis that the Experimental group would subjectively report experiencing APD symptoms more often than the Control group. Each participant answered eleven questions which were related to specific auditory processing complaints and were the same for both groups. A "Yes" answer indicated that the APD symptom in question was experienced by the individual, while a "No" answer suggested he/she did not experience that particular APD symptom. Table 2 displays these results, showing a cumulative 57 "Yes" responses for the Experimental group, compared to 13 "Yes" responses for the Control group.

The Experimental group reported "Yes" more on all of the 11 questions. Of the 11 questions on the questionnaire, questions seven (Are you easily distracted by background noise?), eight (Do you forget names, dates, times, and other information that you recently heard?), and 10 (Is daydreaming or a lack of attention a common problem for you?) received the most "Yes" responses in both groups. Much variability was seen in the frequency of Experimental group "Yes" responses from question to question. Collectively, the range of

Experimental group "Yes" responses ranged from a maximum of 10 to a minimum of 1 at any given question. The collaborative maximum response of the Control group participants was three for any one question with a minimum response of zero "Yes'" for an individual question (Figure 1).

The variability of frequency with which the Experimental group participants responded "Yes" to the ASQ questions indicated that auditory processing complaints differ from individual to individual. This has implications upon the APD test battery performed for each of the affected individuals, and suggests that a different battery of tests should be chosen to address specific complaints. Additional implications exist as to the type of APD remediation strategies chosen. For example, an FM system is a popular compensation strategy recommended for those diagnosed with APD, yet if complaints differ from difficulty attending or understanding in the presence of background noise, remediation strategies other than FM systems should be explored for that individual. The APD test battery used in this study was chosen prior to participant recruitment and remained unchanged for each participant tested.

While results from the ASQ did agree with the hypothesis, results from the battery of four auditory skills tests differed from the hypothesis. Specifically, of the four tests within the chosen battery, statistical analyses found no statistically significant differences between the Control and Experimental groups on any of the APD test measures (PPST, DDT, HINT, and RGDT). However, certain findings from the DDT, the HINT, and the RGDT should be noted.

Throughout the DDT, the participant listened to simultaneous though different stimuli directed to both ears. Because the DDT was designed as a test of binaural integration, it is important to recognize that right and left ear results may show significance independent of the other ear. While there were no significant differences found between the Control and

Experimental groups, there was a statistically significant difference identified between the right and left ear results of the Experimental participants (Table 4, Figures 3 and 4). Implications of this finding might include assessing right versus left dominance, and may even include investigating handedness. Clinically, remediation strategies should focus on repairing and/or strengthening the weaker system, be it right or left.

Additionally, results of the HINT warrant further investigation. This test addresses the auditory processing complaint of distractibility due to background noise, by measuring the participant's Reception Threshold for Sentences (RTS) in dB. The ASQ addressed question number seven, to which both groups had responded "Yes" to most frequently (Table 2, Figure 1). Again, no statistically significant differences were found between the Experimental and Control groups. However, statistical analysis results point to the wide variability of RTS in dB scores of the Experimental group (-11.65 to 10.47 RTS in dB). Results found with the Control group show a much smaller range of scores (6.12 to 11.18 RTS in dB) (Table 5, Figure 5). These results reinforce the idea that individuals with APD may exhibit different symptoms, and perhaps vary in communication abilities within differing types and level of noise.

Like the DDT and the HINT, results of the RGDT indicated no statistically significant differences when comparing the Control and Experimental groups. Yet, a statistically significant difference was found when comparing results of the Experimental group at two of the four tested frequencies, specifically 2,000 Hz and 4,000 Hz (Table 7, Figure 7). This finding was true only for the Experimental group, and serves to remind the reader that the ear does not function linearly in response to different stimuli.

It may be of interest to note the discrepancy between the Experimental group's subjective reports on the ASQ and the objective findings from the PPTS, DDT, HINT, and RGDT results.

Subjectively, the Experimental group reported feeling more affected by APD symptoms than did participants in the Control group. However, on all four portions of the AP test battery there were no statistically significant differences in results between the Control and Experimental groups. Seemingly, the statistically significant differences that were present within the Experimental group's findings on the DDT and the RGDT, in addition to variability among HINT scores, can be attributed to the fact that these tests are sensitive enough to recognize the differences that exist amongst those reporting the auditory processing symptoms. Yet, it stipulates that an APD test battery with greater sensitivity be utilized for investigation of the symptoms reported by the affected individual, therefore ensuring that those with APD are diagnosed as such. Tests with greater specificity would also be useful to ensure that individuals without the disorder are not diagnosed as being affected by it.

Further, it is important that the individual with auditory processing complaints undergo a thorough test battery, yet it is questionable whether the patient's symptoms are even acknowledged. The statistically significant differences within the Experimental group results on the DDT and the RGDT, as well as the variability seen with HINT scores validated that APD complaints should not be overlooked in this population. If an appropriate APD test battery were to be administered, certain remediation and/or compensation strategies would be warranted.

Remediation and/or compensation strategies have been offered throughout APD literature. Again, the specific APD impairment should dictate the remediation and/or compensation strategies employed. Strategies suggested within the literature include both bottom-up and top-down strategies enforced using a team approach with professionals from the health and educational fields. These are in addition to modifying and therefore improving the listening environment in classroom or workplace environments, utilizing an FM system, undergoing auditory training, and practicing strategies to improve communication (American Academy of Audiology, 2010; American Speech-Language Hearing Association, 2005; Baran, 1996; Moore, 2006).

Though there is an abundance of suggested remediation and/or compensation strategies for the individual diagnosed with APD, there is a paucity of research regarding normal hearing, normal functioning young adults reporting difficulty with auditory processing skills. It is unclear whether certain remediation strategies recommended in the literature are intended specifically for the pediatric or the adult population, or if the strategy is appropriate for both. Moreover, the paucity of literature relating to the group in question has prohibited comparisons from being made between the results of this study and previous studies. A wealth of APD literature is available for the following populations: children of school-age, older adults with comorbidities including hearing loss and memory disorders, those who have experienced traumatic head injuries including traumatic brain injuries, adults with reading difficulties, and adults with dyslexia (Amitay, Ahissar, Nelken, 2002; Dawes, Bishop, Sirimanna, Bamiou, 2008; Hari & Kiesilä, 1996; Jerger & Musiek, 2000; Kricos, 2006; Marshall, 1981; Musiek, Baran, Shinn, 2004; Neijenhuis, Snik, Priester, van Kordenoordt, van den Broek, 2002; Sahli, 2009).

Further Research

The findings of this Capstone project, alongside the paucity of research investigating auditory processing skill difficulties in a normal hearing, normal functioning young adult population, lead to the conclusion that ongoing research in this area would be beneficial. The participant population in this study was quite homogenous. Future studies would benefit from a larger sample size, with a more heterogeneous participant population, including an equal number of participants aged 20-30 years and 31-40 years old. Equal numbers of male and female participants are recommended within all experiment populations (for example: Control and Experimental groups), in addition to recruiting participants from many diverse backgrounds. This is in contrast to the current study, which was limited to participants who were predominately female doctoral level graduate students in the 20-30 year age range.

Additional implications for future research exist. For instance, a validated and more comprehensive auditory processing questionnaire should be administered to participants, to ensure that specific APD difficulties can be tested using an appropriate assessment battery. And finally, due to the statistically significant difference found between right ear and left ear results of the Experimental group on the DDT, left ear versus right ear findings and possible implications should be investigated.

Conclusion

Results of the ASQ showed that the Experimental group subjectively reported greater difficulties with AP skills than did the Control group. However, statistical analyses indicated no significant differences between the Control and the Experimental groups on any of the four APD assessments, the PPST, the DDT, the HINT, and the RGDT. Of clinical relevance is that the Experimental group exhibited significant findings on the DDT (differences in the right ear versus left ear results), the HINT (with greater variability of scores within the Experimental group than in the Control group), and on the RGDT (statistically significant differences were present in the Experimental group results between the 2,000 Hz and 4,000 Hz stimuli). These findings demonstrate that complaints mimicking AP difficulties in young adults should not be dismissed. Further, it was implicated that, while the four AP tests chosen for this Capstone comprised an appropriate AP test battery, a test battery should either exhaust all categories of APD or should be tailored specifically to the affected individual's reported complaints.

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Appendix

Washington University in St. Louis
SCHOOL OF MEDICINE

Program in Audiology and
Communication Sciences

Auditory Skill Questionnaire

Please specify whether you are male or female: ____________________
Please specify your age: ____________________
Please specify which of the following levels of education you have completed or are enrolled in:
__ High School __Undergraduate degree __Graduate degree (or higher)

If the question applies to you check "Y" (Yes). If the question does not apply to you, check "N" (No).

Y N

__ __ 1. Do you feel like you have normal hearing?

__ __ 2. Have you ever been diagnosed with any ear disorders, such as ear infections?
If yes, please specify:

__ __ 3. Have you ever received special education services?
If yes, please specify:

__ __ 4. Have you ever been diagnosed with any neurologic disorders?
If yes, please specify:

__ __ 5. [Even though you have normal hearing] do you feel as though you frequently ask for repetition?

__ __ 6. Do you often experience difficulty following ***spoken*** directions?
If yes, do you have difficulty with **simple** directions, **multistep** directions, or **both**? (Please circle your answer).

__ __ 7. Are you easily distracted by background noise?

__ __ 8. Do you forget names, dates, times and other information that you recently ***heard***?

__ __ 9. Do you ever experience difficulty with spelling and/or reading?

__ __ 10. Is daydreaming or a lack of attention a common problem for you?

__ __ 11. Is rapid speech difficult for you to understand?

__ __ 12. Do you have difficulty locating where a sound is coming from?

__ __ 13. Do you say "huh" or "what" a lot?

__ __ 14. Do you find that you are unorganized or messy?

__ __ 15. Do you sometimes have difficulty understanding subtle meanings within social conversations or in social gatherings?

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Questions adapted with permission from the Auditory Processing Disorder: Behaviors of "at risk" Children from the Center for Hearing and Speech.

Table 1
Participant Demographics

Characteristics	Control Group (N=12)	Experimental Group (N=12)	Total (N=24)
Age Range	21-38 years	20-29 years	
Female Participants (#)	9	12	21
Male Participants (#)	3	0	3
20-30 years	10	12	22
31-40 years	2	0	2
Mean Age & Standard Deviation	26.25 years +/- 5.5 years	23.83 years +/- 2.59 years	25.04 years +/- 4.38 years

Table 2
Questionnaire Results Showing Number of "Yes" and "No" Responses as a function of Group

		# Yes Responses		# No Responses	
Question #		**Control**	**Exp.**	**Control**	**Exp.**
5	[Even though you have normal hearing] do you feel as though you frequently ask for repetition?	1	5	10	6
6	Do you often experience difficulty following spoken directions?	0	3	11	8
7	Are you easily distracted by background noise?	3	10	8	1
8	Do you forget names, dates, times and other information that you recently heard?	3	7	8	4
9	Do you ever experience difficulty with spelling and/or reading?	0	3	11	8
10	Is daydreaming or a lack of attention a common problem for you?	3	8	8	3
11	Is rapid speech difficult for you to understand?	1	5	10	6
12	Do you have difficulty locating where a sound is coming from?	0	1	11	10
13	Do you say "huh" or "what" a lot?	0	5	11	6
14	Do you find that you are unorganized or messy?	1	6	10	5
15	Do you sometimes have difficulty understanding subtle meanings within social conversations or in social gatherings?	1	4	10	7
Total		13	57	108	64

Table 3
Pitch Pattern Sequencing Test Results

Group	Median	Min-Max
Control (N=12)	100%	85-100%
Experimental (N=12)	96.7%	80-100%

Table 4
Dichotic Digits Test- Right and Left Ear Results

Group	Ear Results	Median	Min-Max
Control (N=12)	Right	100%	95-100%
	Left	98.8%	90-100%
Experimental (N=12)	Right	97.5%	87.5-100%
	Left	95%	90-100%

Table 5
Hearing in Noise Test Results expressed in Reception Threshold for Sentences (dB)

Group	Median	Min-Max
Control (N=12)	7.82 RTS (dB)	6.12-11.18 RTS (dB)
Experimental (N=12)	7.06 RTS (dB)	-11.65-10.47 RTS (dB)

Table 6
Random Gap Detection Threshold test Results (between group comparison)

Group	Median	Min-Max
Control (N=12)	25 msec.	14-45 msec.
Experimental (N=12)	14 msec.	11-40 msec.

Table 7
Random Gap Detection Threshold test results (comparison between frequencies)

Frequencies	**Control (N=12)**	**Experimental (N=12)**	**p-value***
500Hz	5.0 (2-15)	3.5 (2-10)	0.236
1000Hz	5.0 (2-20)	3.5 (2-15)	0.214
2000Hz	5.0 (2-10)	5.0 (2-15)	0.682
4000Hz	5.0 (5-10)	5.0 (2-10)	0.078

Figure 1
Bar graph comparing Control group versus Experimental group frequency of "Yes" responses on the ASQ

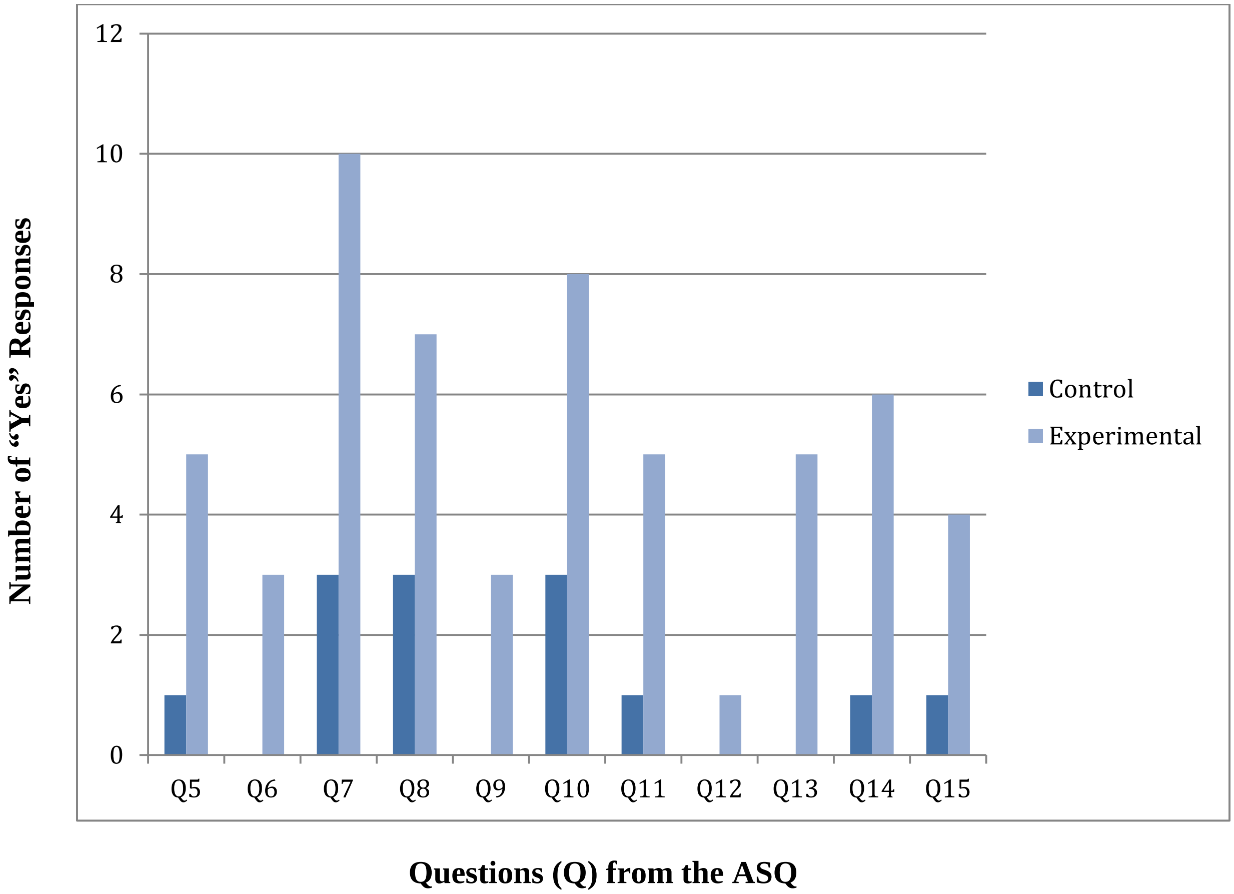

Figure 2
Box-plot displaying Pitch Pattern Sequencing Test results for Control and Experimental groups

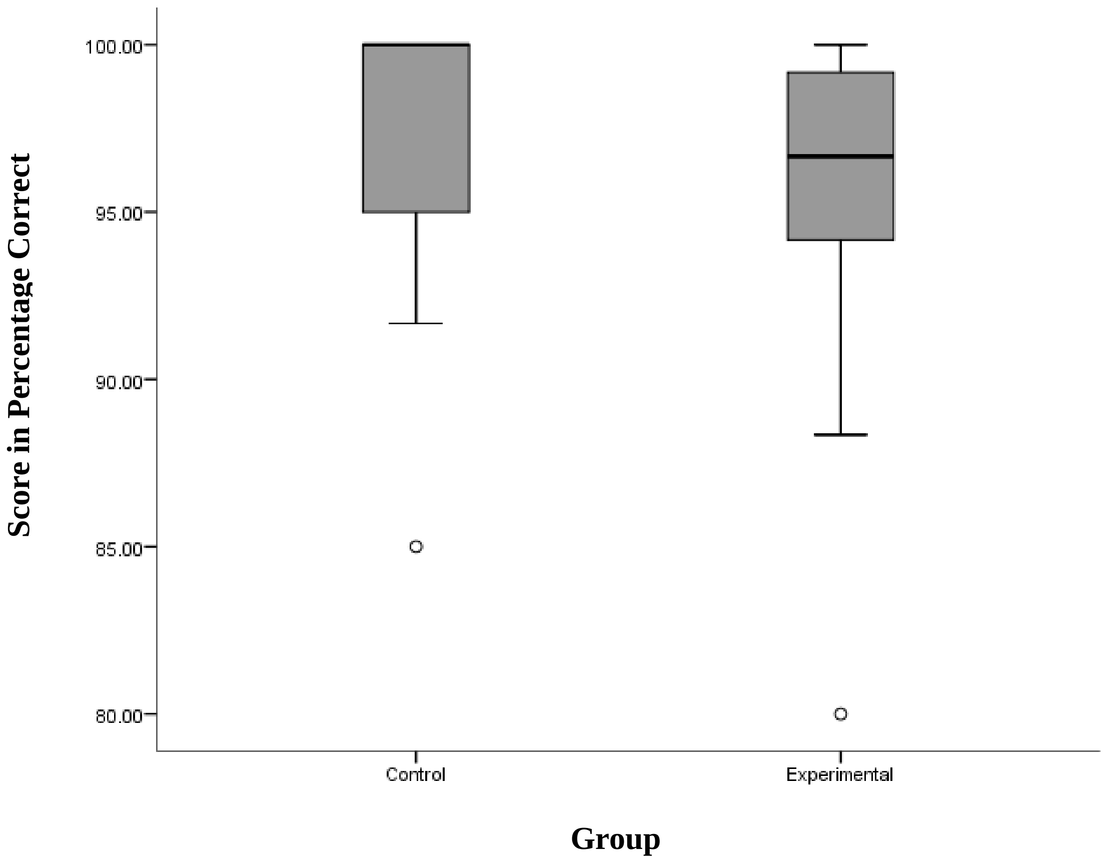

Figure 3
Box-plot displaying Dichotic Digits Test results for Control and Experimental groups (Right ear)

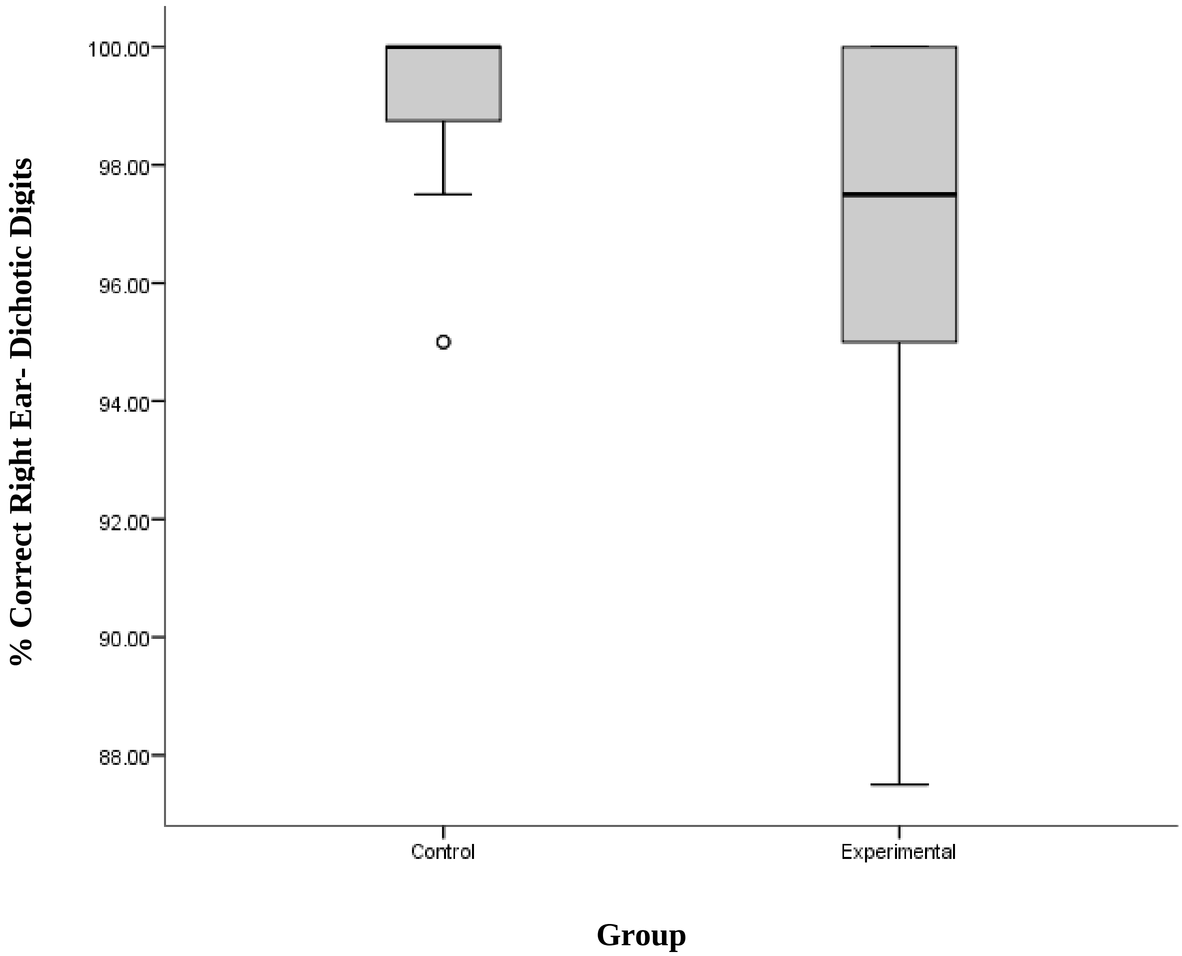

Figure 4
Box-plot displaying Dichotic Digits Test results for Control and Experimental groups (Left ear)

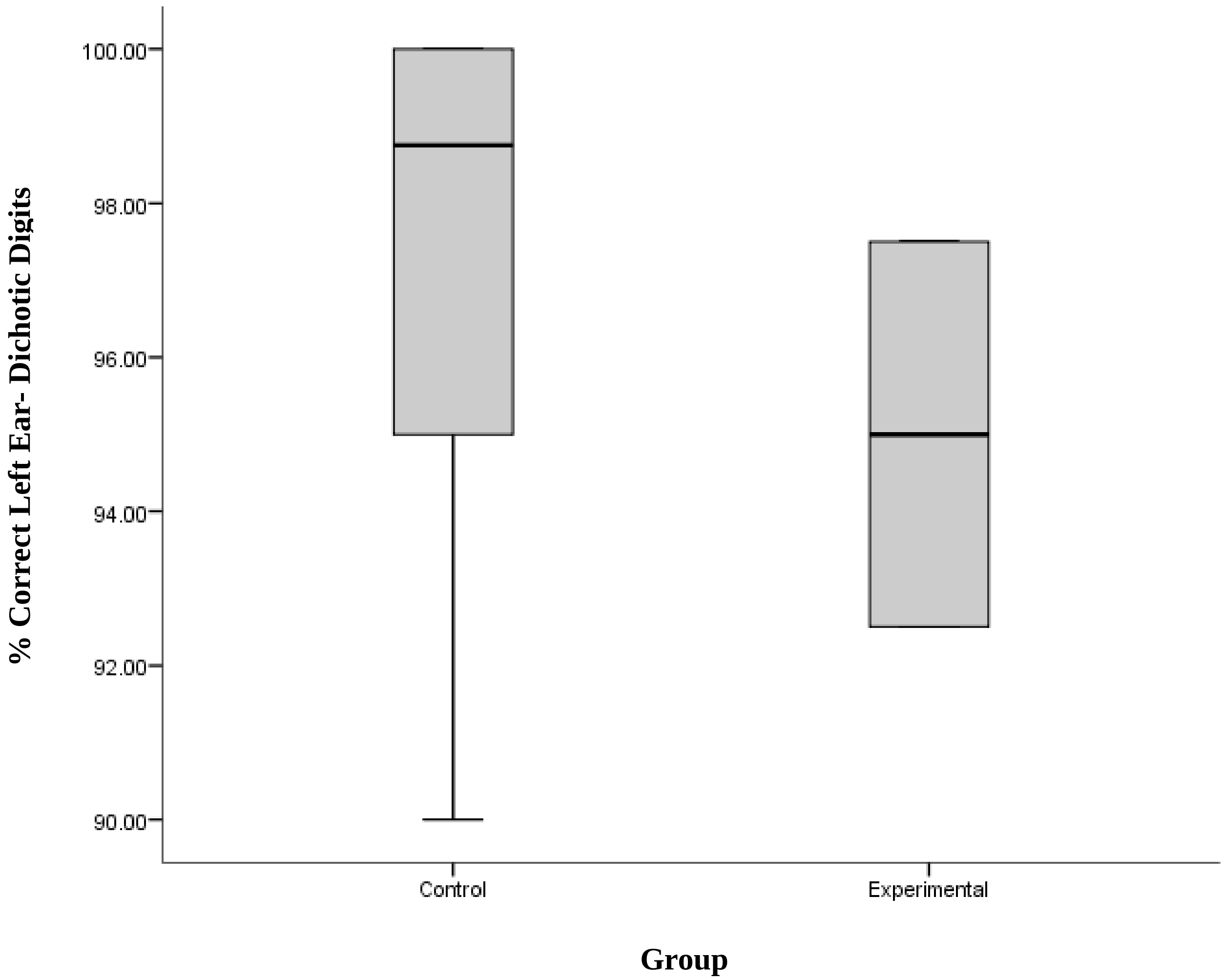

Figure 5
Reception Threshold for Sentences (RTS) in dB, obtained for Control and Experimental groups after administration of the Hearing in Noise Test

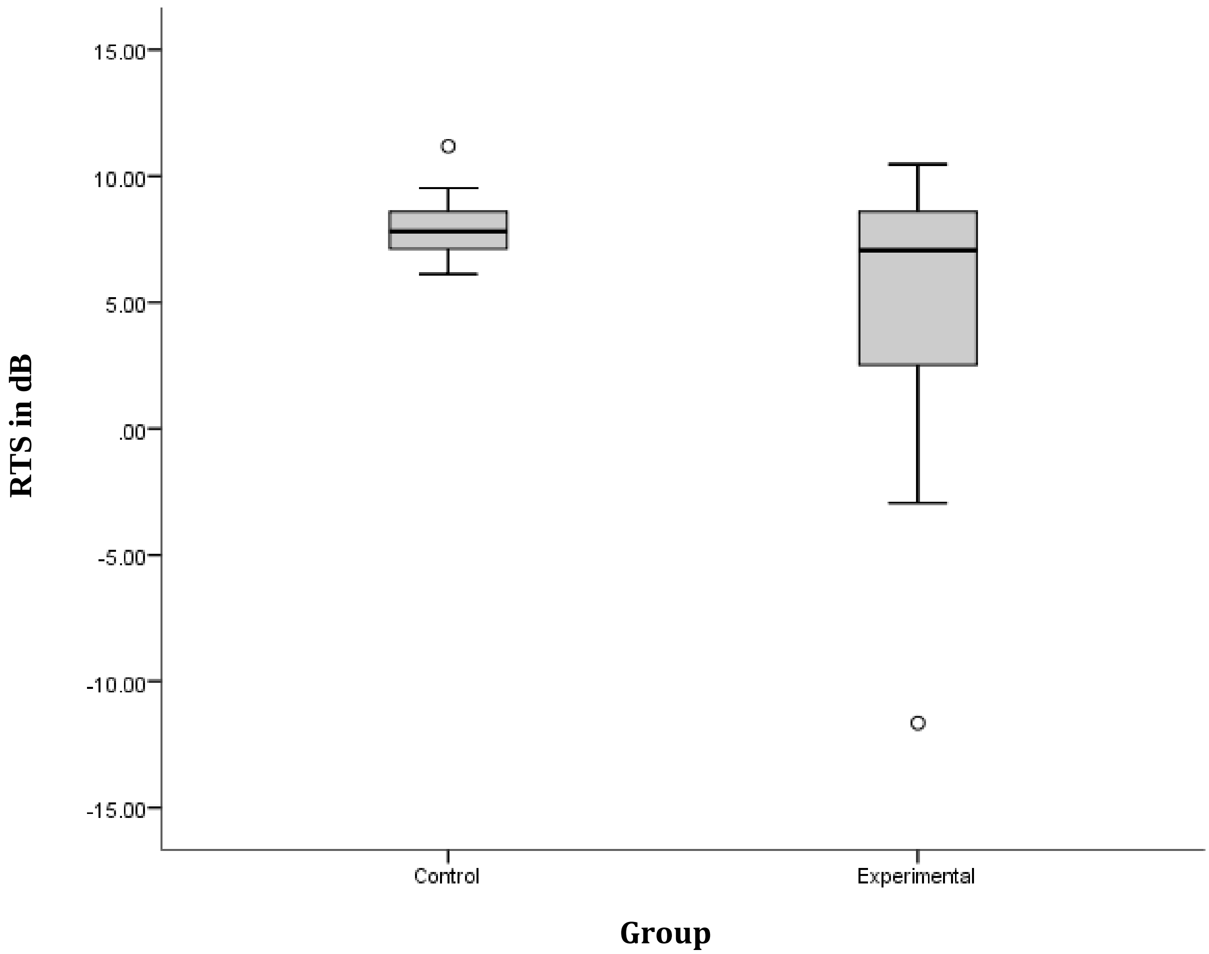

Figure 6
Random Gap Detection test results for Control and Experimental groups expressed in milliseconds (500 Hz-4,000 Hz)

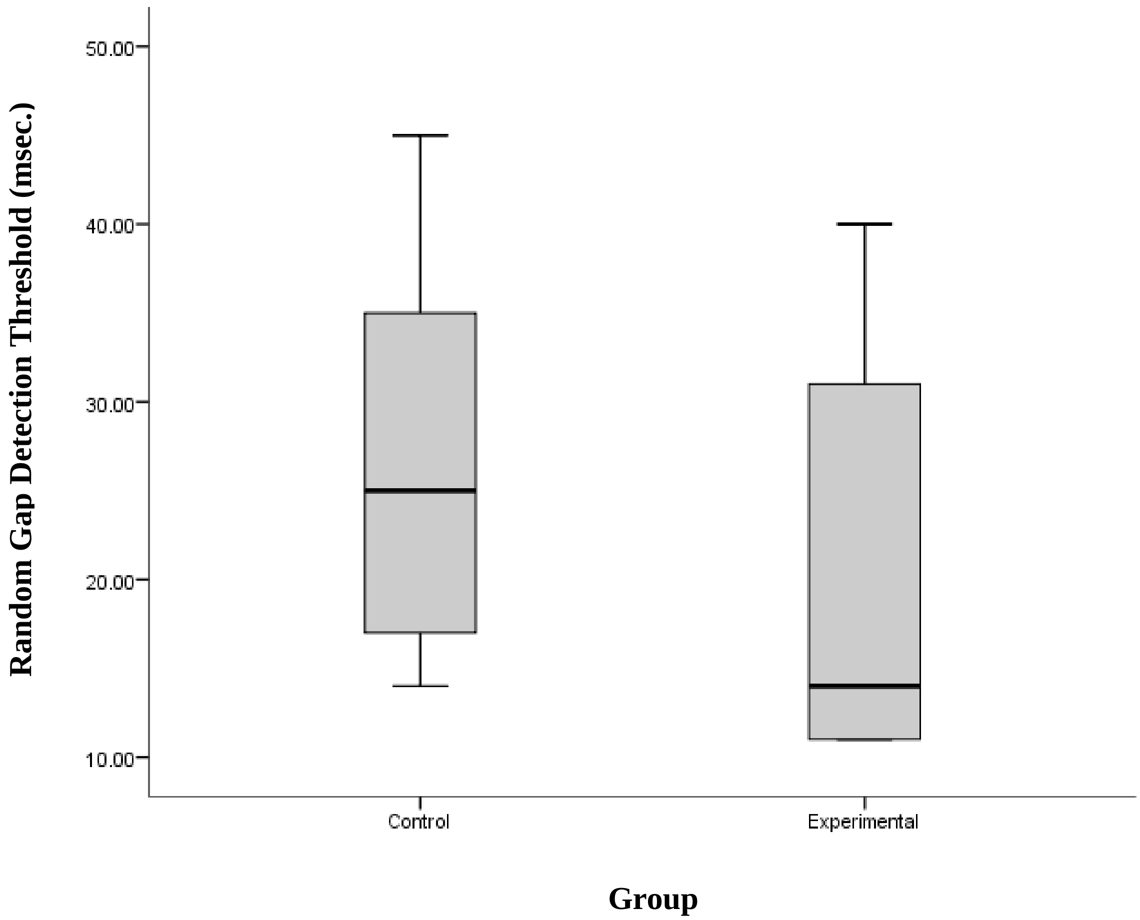

Figure 7
Box-plot results showing the distribution of Random Gap Detection Thresholds of the Control group and Experimental group at each frequency