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THE CLINICAL APPLICATION OF PROGRESSIVE FILTERING IN NORMAL AND DISORDERED POPULATIONS

by

Sarah M. Johnson, B.S.

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Audiology

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We hereby recommend that the dissertation prepared under our supervision by SARAH M. JOHNSON, B.S.

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THE CLINICAL APPLICATION OF PROGRESSIVE FILTERING IN NORMAL AND DISORDERED POPULATIONS

be accepted in partial fulfillment of the requirements for the Degree of

DOCTOR OF AUDIOLOGY

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ABSTRACT

The present study examined the effect of progressive filter testing in children with normal auditory processing skills and children with (central) auditory processing disorders [(C)APD]. The primary purpose of this study was to determine if a new screening procedure designed by the investigator called Progressive Filtering would differentiate between a control group (i.e. children with normal auditory processing skills) and an experimental group [children with (C)APD] . Twenty subjects (age 6 to 14 years) participated in the study. All subjects received an audiological examination, an auditory processing test battery, and the Progressive Filtering screening tool. Results indicated that the investigator-designed Progressive Filtering screening tool did differentiate between the control and experimental groups for certain frequencies.

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Author Sarah Johnson

Date 3-25-11

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CHAPTER I

INTRODUCTION

Children and adults with auditory processing problems experience difficulty processing speech and auditory stimuli in numerous situations. Consequently, they may be missing many components of a message that can impact academic, social, and vocational performance. Although research has been conducted on (Central) Auditory Processing Disorders [(C)APD] for numerous years, almost every area concerned with (C)APD remains controversial. For instance, Katz (2002) stated that there still remains a lack of a clear, universal definition for this disorder, even though there have been many attempts to develop such a definition. In 1996 and 2005, a task force developed by the American Speech-Language-Hearing Association (ASHA) defined and described (C)APD. (C)APD is defined as "a deficit in one or more of the following: difficulties in the processing of auditory information in the central nervous system (CNS) as demonstrated by poor performance in one or more of the 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" (ASHA, 2005, p. 1). Jerger and Musiek

(2000) defined this disorder as "a deficit in the processing of information that is specific to the auditory modality. The problem may be exacerbated in unfavorable acoustic environments. It may be associated with difficulties in listening, speech understanding, language development, and learning" (Jerger & Musiek, 2000, p. 468).

A second controversial area—underlying etiology—was discussed by Chermak and Musiek (1997). They describe (C)APD not as a unitary disease, but rather a label of functional deficits. They state that (C)APD is a deficit that can be in conjunction with lesions or pathologies of the CNS or neurodevelopment disorders. They describe three etiologies of (C)APD all of which were associated with learning disabilities. Specifically, (C)APD may result from neuromorphological disorders, maturational delays of the CNS, or as the result of a neurological or neurodegenerative disorder.

Symptomology is another area which much debate and differences of opinions have been reported. According to Chermak and Musiek (1997), the symptoms of (C)APD vary among the different causes of (C)APD as mentioned above. As previously mentioned, the ASHA Task Force (1996, 2005) listed specific difficulties that can be experienced (i.e., temporal processing, distorted speech). Yalcinkaya and Keith (2008) describe that early symptoms of (C)APD may include "delayed language development, phonologic and reading disorders, problems of learning through the auditory channel, poor auditory memory span, and poor auditory sequential memory" (Yalcinkaya & Keith, 2008, p. 101). In addition they also described that children with (C)APD may behave as if they have a hearing loss, despite normal hearing; have difficulty with auditory discrimination of phonemes, difficulty with remembering and manipulating phonemes, difficulty understanding speech in the presence of background noise, and difficulty with auditory memory and remembering a list of directions; demonstrates scatter results across a speech-language test battery with a weakness in auditory-dependent areas; poor listening skills; distractibility or restless behavior in listening situations; inconsistency in auditory awareness; receptive or expressive language disorder; difficulty understanding rapid speech; and poor musical abilities. Other symptoms of (C)APD that may be seen in young children are described by Keith (2009) as "poor expressive and receptive language abilities; poor reading, writing, and spelling; difficulty taking notes; poor phonics and speech sound discrimination; poor ability to memorize; and/or problems following a sequence of instructions" (Keith, 2009, p. 1). Martin and Clark (2006) also state that other signs and symptoms of children with a (C)APD can include "poor listening skills, short attention spans, seemingly poor memories, reading comprehension, difficulty in linguistic sequencing, and problems in learning to read and write" (Martin & Clark, 2006, p. 331).

Lastly, there is currently no 'gold standard' or test battery approach that is currently used or recommended by the experts (Schow & Chermak, 1999). Many test battery approaches have been developed over the years for (C)APD and are in the areas of lexical decoding, phonological decoding, tolerance-fading memory, auditory integration, sequencing, and auditory attention (Katz, 2002; Keith, 2000), to name a few. Although there are a number of testing protocols, questionnaires, checklists, and other procedures (e.g. *Test for Auditory Processing in Children – Revised and Test for Auditory Processing in Adults – Revised (SCAN-C/A), Staggered Spondaic Words (SSW), Time-Compressed Speech*, etc.) that have been suggested to identify individuals who are candidates for a (central) auditory processing evaluation, there continues to be a need for valid and efficient screening testing tools for (C)APD (ASHA, 2005). One area receiving little attention is filtered speech/distorted speech. Distorted or degraded speech is defined as, "signals that have been altered in any of several ways to reduce its redundancy" (Stach, 2003, p. 78). With the distortion of the speech signal there are often decreased speech recognition abilities contralateral to the central lesion (Martin & Clark, 2006).

There are very few standardized tests that include filtered speech. For instance, tools that currently include filtered speech is the *SCAN-C/A* and updated *SCAN-3* (Keith; 2000, 2009), and filtered word lists developed by Auditec of St. Louis. In the *SCAN-C* protocols, the filtered speech subtest has a low-pass filter with a cutoff of 1000 Hz with a rolloff of 32 dB per octave. The test includes 20 monosyllabic words presented to each ear separately and provides age specific normative data. The filtered word lists from Auditec of St. Louis is developed specifically for adults and lacks any significant explanation of how the test was normed. There is very limited information or normative data available for children using filtered speech.

Martin and Clark (2006) explained the importance of filtered speech tests and how they are clinically applied. According to these authors, filtered speech is a type of distorted speech stimulus that aids in the diagnosis of a (C)APD as well as a CNS lesion . As stated by Martin and Clark, standard monosyllabic speech recognition tests without any distortion do not assist with the identification of central auditory lesions, primarily at the level of the temporal lobe.

Filtered speech can be accomplished by passing the speech signal through a filter that rejects certain frequencies. In general, there are four different types of filters: high-pass filters that allow the high frequencies to pass while rejecting the lows, a low-pass filter that passes the lows and rejects the highs, a band-pass filter that rejects both high and low frequencies above and below a certain frequency range, and a band-reject filter that passes both high and low frequencies above and below a certain frequency range. The cutoff frequency is the precise frequency in which the filtering takes place. Studies have been conducted to determine the clinical application of filtered speech (Karlsson & Rosenhall, 1994) as well as the discrimination abilities of different groups (Nagafuchi, 1974). As will be discussed in the literature review, little information is provided in regards to how children perform over a wide range of filtered speech. In this dissertation, a novel technique will be described—Progressive Filtering. The investigator-designed Progressive Filtering screening tool consists of phonetically balanced word lists of monosyllabic words filtered at different frequencies (i.e., 750 Hz, 1000 Hz, 2000 Hz, and 4000 Hz). This tool is being investigated to determine if it is sensitive and specific enough to differentiate individuals with normal auditory systems from those identified as having a (C)APD. Therefore, the hypothesis of this dissertation is that this tool will differentiate between individuals with and without (C)APD.

CHAPTER II

REVIEW OF THE LITERATURE

(Central) Auditory Processing Disorders [(C)APD]

As mentioned previously, all areas of central auditory processing and its disorders currently remain controversial. The development of a universal definition is one main area that remains ongoing. The American Speech-Language-Hearing Association (2005) created a widely used definition of a (Central) Auditory Processing Disorder ([C]APD) and defined it "as difficulties in the processing of auditory information in the central nervous system (CNS) as demonstrated by poor performance in one or more of the 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" (ASHA, 2005, p.1). One aspect of this definition—"auditory performance with degraded acoustic signals" (ASHA, 2005, p. 1)—is the main focus of this present study. Little research exists as to the efficacy of filtered speech as a stand-alone test indentifying functional deficits in children with (C)APD.

Filtered Speech

Martin and Clark (2006) discussed the importance of filtered speech tests and how they are clinically applied. The authors explained that standard speech recognition tests without any distortion presented monaurally are not sensitive enough to identify central lesions (e.g., brainstem and temporal lobe lesions). It has been found by many researchers (e.g., Bocca, 1955, 1959; Kimura, 1961, 1963) that distortion of a speech signals often decreases speech recognition abilities in the ear contralateral to the central lesion.

Filters

Filtered speech can be accomplished by passing the speech signal through a filter that rejects a specific range of frequencies. A filter is defined as "a device that changes the spectrum of a signal" (Plack, 2005, p. 244). When discussing filters, there is also a discussion of a roll-off value. A roll-off value is described as the "rate of attenuation" by the filters (Yost, 2007, p. 56). The rate of attenuation refers to how fast the signal is attenuated below the cutoff frequency. Yost (2007) explained that there are four different types of filters: high-pass, low-pass, band-pass, and band reject. High-pass filters allow the high frequencies above a certain point and attenuate the lows below a certain frequency as seen in Figure 1.

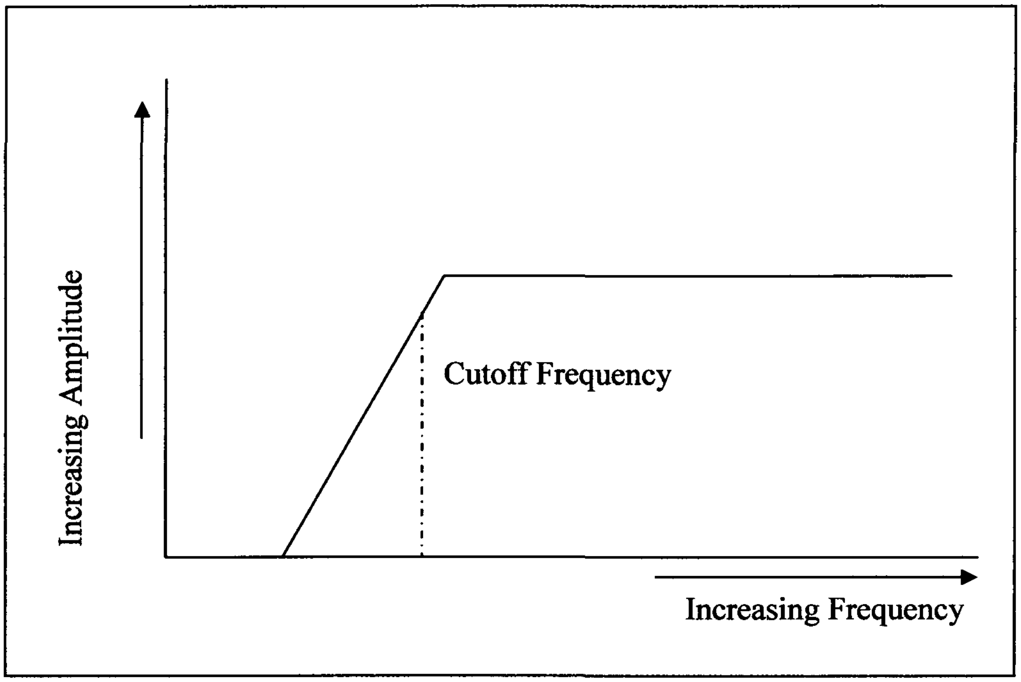

Figure 1. High-Pass Filter

A low-pass filter passes the low frequencies below a certain point and rejects the high frequencies beyond that certain point as seen in Figure 2.

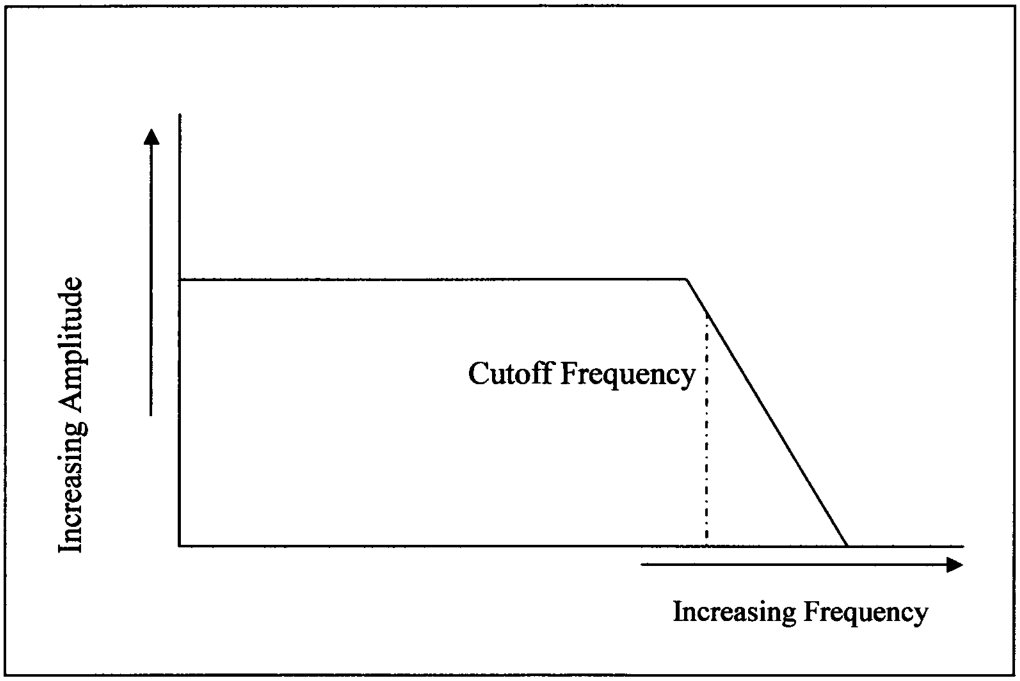

Figure 2. Low-Pass Filter

A band-pass filter rejects both high and low frequencies above and below a certain range. The cutoff frequency is the precise frequency in which the filtering takes place in a band-pass filter as seen in Figure 3.

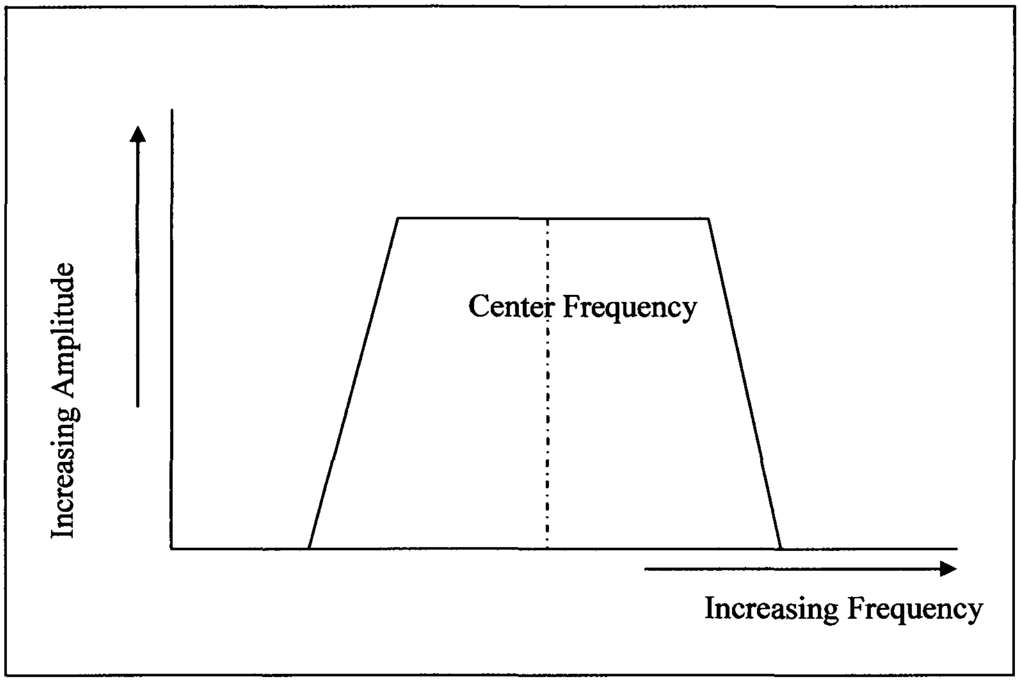

Figure 3. Band-Pass Filter

A band-reject filter passes the frequencies between the low frequency value and the high frequency value as seen in Figure 4.

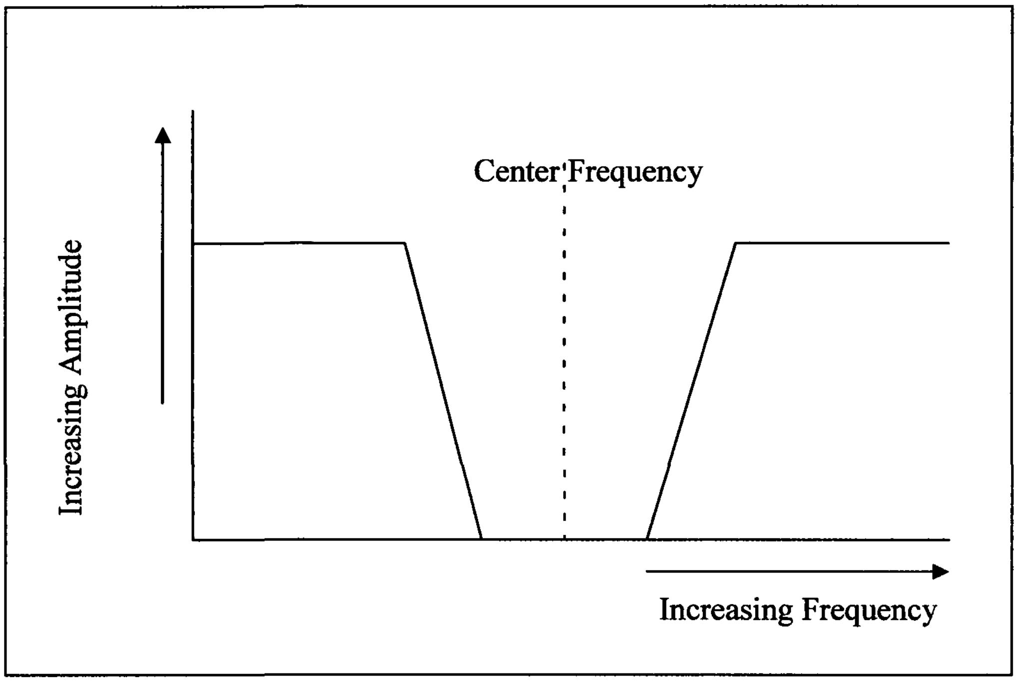

Figure 4. Band-Reject Filter

Filtered speech is developed when speech signals are passed through one of these four types of filters. Martin and Clark (2006) state that filtered speech taxes the central auditory nervous system (CANS), and can therefore be used to determine if a temporal lobe or central lesion are present. Keith (1999) further emphasizes that individuals with (C)APDs may have difficulties with many types of auditory distortion, such as acoustic filtering, and such testing and treatment options should be made available in these deficit areas.

Research on Filtered Speech

Although filtered speech has been used in conjunction with other tests within a test battery, it has rarely, if ever, been used as a unitary test of (C)APD. Filtered speech has been used to determine brainstem lesion location (Stephens & Thornton, 1976), identification of temporal lobe lesions (Bocca, 1955, 1958; Jerger, 1960), assessing brainstem integrity (Smith & Resnick, 1972), inclusion in Central Auditory Nervous System (CANS) testing (Karlsson & Rosenhall, 1994; Mueller & Bright, 1994), to evaluate degree of central auditory processing ability (Keith & Jerger, 1991; Keith, 1999, 2000; Musiek & Geurkink, 1980; Rintelman, 1985), inclusion in certain tests like the SCAN-C (Keith, 1986) and SCAN-3 (Keith, 2009), determining level of learning disabilities (Nagafuchi, 1974), used in presbyacusis studies (Jerger, 1960), in occupational studies (Spieth & Webster, 1955), and in conjunction with masking studies (Scott, Green & Stuart, 2001).

Anatomical Studies

A more detailed look at these studies proves that filtered speech is a sensitive way to determine specific processing abilities associated with site-of-lesion testing. In early studies conducted by Bocca (1955, 1958), he determined that filtered speech was an adequate way to locate temporal lobe lesions contralateral to that of the affected ear. In a similar study, Jerger (1960) also found that filtered speech was sensitive in locating temporal lobe lesions. In this study Jerger presented a low passed filtered word list presented monaurally to individuals with unilateral temporal lobe lesions. The subjects performed significantly lower on the side opposite the lesion. Thus, Jerger (1960) confirming Bocca's (1955, 1958) earlier findings in that filtered speech has the ability to assist in localizing temporal lobe lesions contralateral to that of the affected ear.

Palva and Jokinen (1975) determined the clinical application of binaural versus monaural filtered speech tests by evaluating the results of filtered speech tests in subjects with a variety of retrocochlear and central auditory lesion. Three hundred and three subjects were used for this study (their ages were not reported). These subjects were divided into five groups based on location of the lesion: central lesions, intracranial tumors, multiple sclerosis, skull trauma, and intracranial vascular disorders. The filtered speech test included two bands of speech: 480-720 Hz and 1800-2400 Hz. The word lists were designed so that both bands were presented together either monaurally or binaurally. The order that the lists were presented were: the first word was monaural to the right ear, second to the left ear, and the third word was presented binaurally. This order of presentation was carried out for 90 words. The test was arranged this way so that the monaural and binaural presentations were mutually comparable. After the tests presentations were completed, the scores were compared for each of the four groups.

Based on the results, Palva and Jokinen (1975) concluded that the most common finding in the filtered speech test was an asymmetry in discrimination abilities, which was expected since all subjects had a unilateral lesion. However, monaural presentation was considered to be the best way to present filtered speech tests, as it showed the consequences of a lesion at any level of the perceptive auditory system. In addition, the authors concluded that a monaurally presented signal may be handled unilaterally while a binaurally presented signal may be fused together and deciphered by either hemispheres of the brain.

In a similar study, Stephens and Thornton (1976) conducted a study to determine test results in patients with known brainstem lesions. Twenty-two patients with diagnosed neurological disorders involving the brainstem were used for this study. In this study high-pass and low-pass filtered speech discrimination tests were used to help determine central auditory function. Test results showed that filtered speech, along with other screening tools, was sensitive enough to determine brain lesion location.

In another site-of-lesion study, Karlsson and Rosenhall (1994) determined the clinical application for distorted speech audiometry by evaluating the results of distorted speech tests in subjects with verified retrocochlear lesions or lesions of the CANS. Eighty-three native Swedish speakers (age 10 to 65 years) were used for this study. Inclusion criteria for this study were: a verified CANS lesion based on a neurological examination, pure-tone thresholds of 35 dB HL or better, and speech reception thresholds of 80% or better in a quiet situation. These subjects were divided into four subgroups based on the location of the lesion: cerebellopontine angle tumor (CPA), brainstem multiple sclerosis (MS) or brainstem tumor, vascular brainstem lesion, or temporal lobe lesion. Four different distorted speech tests were used for this study. Each test was comprised of 25 sentences with four key words in each sentence. There were four different distorted speech conditions, one being filtered speech. The filtered speech test was the fourth stimulus. The sentences were passed through a band-pass filter that was one third of an octave wide and had center frequencies of .5, .64, and .8 kHz. A comparison between the diseased (worse) ear and the contralateral (better) ear was conducted on the positive lesion groups. When compared between ears, results showed: CPA group had no significant difference between ears on any measure, brainstem MS and tumor group had reduced scores in the worse ear on all measures, vascular brainstem lesion group showed reduced scores for the worse ear on all but one test, and the temporal lobe lesion group showed significant differences for interrupted speech, time-compressed speech, and filtered speech tests. The scores were also compared to a control group, which consisted of 416 subjects (age 19 to 65 years) that had pure tone thresholds of 20 dB HL or better and no known lesions. The control group was not gathered strictly for this study, but was selected from a previous study conduct by Møller in 1973. When compared, results showed: CPA group showed significantly lower scores for the interrupted speech and time-compressed speech tests; brainstem MS and tumor group showed reduced scores on all tests; vascular brainstem lesion group had significantly lower scores on all tests except the interrupted speech test; and temporal lobe lesion group showed significant differences for all tests except the interrupted speech test. Based on these results, Karlsson and Rosenhall (1994) concluded that time compressed speech, filtered speech, and interrupted speech should be recommended when aiding in the diagnosis of central auditory lesions. Therefore, filtered speech was concluded to be sensitive enough when aiding in the diagnosis of central auditory lesions.

Functional Central Auditory Processing Studies

Another way filtered speech is clinically significant is in the area of (C)APD and how it impacts an individual's ability to function in daily activities. In an early (C)APD study Musiek and Geurkink (1980) performed testing on children that had normal peripheral hearing but were referred for further testing due to the question of a hearing loss. Five children with auditory processing deficits were used for this study. A test battery approach was used for each child that consisted of rapidly alternating speech, binaural fusion, low pass filtered speech, competing sentences, SSW, dichotic digits, and frequency patterns. The filtered speech subtest within this screening was low-pass filtered at 500 Hz with an 18 dB roll-off per octave. This subtest was determined to be clinical significant in assisting in a diagnosis of (C)APD. However, Musiek and

Geurkink (1980) also stated that the overall medical and education deficits should be taken into consideration when diagnosing a (C)APD.

Many group comparison studies have been conducted to determine differences in performance on (C)APD test batteries. In one study Ferre and Wilber (1986) determined differences in performance between children with normal auditory functioning (control group) and children with learning disabilities (experimental group). Thirteen children were included in the control group and 26 children in the experimental group. The groups were given the same test battery consisting of low-pass filtered speech, binaural fusion, time-compressed speech, and dichotic speech. The low-pass filtered subtest consisted of a 25 item word list where each word was passed through a 1000 Hz low-pass filter with a rejection rate of 48 dB per octave. Results of this study showed that filtered speech was sensitive enough to differentiate between the control and experimental groups.

Perhaps one of the most popular filtered speech tests is within the *SCAN-C/A* developed by Keith (2000). The filtered speech subtest within the *SCAN-C/A* consisted of forty words that were low-pass filtered at 1000 Hertz (Hz) with a roll-off of 32 decibels (dB) per octave. Keith obtained normative data for the *SCAN-C* by testing 650 children age 5 years to 11 years 11 months. The *SCAN-C/A* was used for the present study to differentiate between children with and without a (C)APD.

Other Filtered Speech Clinical Studies

Nagafuchi (1974) compared the filtered speech discrimination abilities of normal children with that of the individuals with decreased mental abilities. Twenty children (age 4 to 5 years) were used for the control group and all were considered to be within normal limits for intelligent quotient (IQ) measures. The experimental group consisted of 68 children (age 8 to 18 years) and had mental ages that ranged from 4 to 10 years and the IQ scores ranged from 50 to 75. All subjects were native Japanese speakers and had normal peripheral hearing bilaterally. All subjects were given a standard speech test to determine the intensity level at which 100% of the words were correctly identified. The filtered word list consisted of 20 phonetically balanced words that were filtered at three levels: low-pass filtered below 1200 Hz, high-pass filtered above 1700 Hz, and band-pass filtered from 1200 to 2400 Hz. The filter had 19 band frequencies that ranged from 37.5 to 19200 Hz. The filtered words were recorded at 5 second intervals. The filtered word lists were presented at 10 dB sensation level (SL) above their obtained level in standard speech audiometry. The authors found that by filtering the speech there was an overall decrease in the sound intensity when compared to unfiltered speech.

Nagafuchi (1974) found that for the standard speech audiometry test, discrimination improved as intensity increased for all subjects. However, the children with normal IQ's achieved 100% intelligibility at an average of 40 to 50 dB SL, whereas, the children with lower IQ's did not achieve 100% until about 10 to 20 dB SL above average of the normal children. Results for the intelligibility of low-pass filtered words below 780 Hz showed that both groups scored very poor (i.e., below 70%), and there was little significant differences between the two groups. Low-pass filtered words above 780 Hz scored closer to that of the high-pass and band-pass filtered words. The author found that high-pass filtered words showed increased intelligibility scores when compared to the low-pass words for both groups, however, the scores gradually improved as mental age increased. The control group scored exactly the same on the band-pass filtered words as the high-pass filtered words. However, for the experimental group, the scores fell between the low-pass scores and the high-pass scores of the control group. Based on these results, it was concluded that auditory immaturity was the primary cause of the low intelligibility scores on the filtered speech word lists. It was also concluded that scores in general were lower in experimental group, which was determined to be a result of higher distractibility, a narrower attention span, and an underdeveloped auditory system.

In another study, Moore, Adams, Dagenais, and Caffee (2007) determined the effect of different listening conditions on speech rate judgment (e.g., competing speech, distorted speech, time-compressed speech, and filtered speech). Twenty native English speakers (age 20 to 40 years) were used for this study. All subjects had normal peripheral hearing bilaterally, normal otoscopic findings, and no history of speech or language deficits. All subjects underwent a preliminary screening using speech stimuli to determine their most comfortable listening level (MCL). Each subject was then seated in front of a computer with a mouse and instructed to listen to each speech stimuli and point to the choice he/she felt was closest to how the perceived the rate of speech. The testing procedure consisted of time-altered speech stimuli manipulated to represent four listening conditions: a non-degraded ideal listening environment with no external interferences, a reverberant condition that sounded similar to communication in a reverberated room, a low-pass filtering condition that sounded similar to communication from another room, and a band-pass filtering condition similar to communication over a telephone. In the conditions that did not include filtered speech, a sentence from the *Quick Speech in Noise (QuickSIN)* test was used. The *QuickSIN* was recorded with the sentence on one channel and the noise recorded on the other channel simultaneously. For the purposes of this study, the original version of the *QuickSIN* was digitally manipulated so that the speech stimulus was presented binaurally. The speech stimulus was then time altered to produce speech rates of 90 words per minute (wpm) to 250 words-per-minute (wpm) in 8 wpm steps. The filtered speech stimuli were altered using the digital Blackman filter. The band-pass filtered condition was set to pass frequencies from 3000 to 4000 Hz, and the low-pass filter was set to allow frequencies below 825 Hz. The stimuli were presented to each subject at their pre-determined MCL. The subjects had five choices of speech rate perception: too slow, slow but ok, preferred, fast but ok, and too fast. Two experimental trials of the tests were presented to each subject prior to the stimuli in order to evaluate subject reliability. Results showed high reliability between subjects (e.g. <0.001). For data analysis purposes, the answer choices were assigned numerical values: 1 = too slow, 2 = slow but ok, 3 = preferred, 4 = fast but ok, and 5 = too fast. Results showed preferred speech rate scores were the same for the non-degraded, low-pass filtering, and band-pass filtering conditions. However, for the reverberant listening condition, the preferred speech rate was slower than the other three conditions. It was determined that in a reverberated listening condition the speech signal could not be easily predicted, therefore causing extra time and effort to process the signal, resulting in preferred rate of speech in this situation to be slower. Based on these results, Moore et al. (2007) determined that speech rate judgment was affected by listening conditions. Furthermore, this study validated that when developing and presenting auditory stimulus in a rehabilitative or training setting, the listening condition may need to be taken into consideration.

A more recent study including filtered speech was conducted by Scott, Green, and Stuart (2001). In this study twenty young adults (mean age 23.4 years) with normal peripheral hearing were presented with word lists that were low-pass filtered at 1500, 2000, and 1000 Hz with a roll-off of 48 dB per octave. In this study filtered words were presented in combination with different conditions in order to determine word recognition in noise to examine temporal resolution in individuals with simulated hearing loss. The filtered word lists were presented to the subjects in three different conditions: in quiet; in the presence of continuous broadband noise; and in the presence of interrupted broadband noise. The results of this study showed that individuals with high frequency hearing loss may have poorer word recognition abilities due to their dependence on low frequency hearing channels and loss of temporal resolution. This study concluded that filtered speech was clinically significant when combined with masking noise to determine word recognition abilities in patients with a high frequency hearing loss.

Singer, Hurley, and Preece (1998) determined the clinical application of the central auditory processing (CAP) individual test efficacy, test battery efficacy, and cost effectiveness of various test batteries. Two-hundred-thirty-eight subjects (age 7 to 13 years) were used for this study. Inclusion criteria for this study were: normal air conduction thresholds of 15 dB HL between 250-8000 Hz, normal middle ear function, and normal speech and language abilities. The subjects were divided into two groups: the normal learning (NL) abilities group and the classroom learning disability (CLD) group. The subjects in the NL group all had normal classroom function in all areas of academic achievement. The subjects included in the CLD group had a history of reading problems, difficulty following verbal instructions, and difficulty paying attention in class. All of the subjects in the CLD group had also been previously referred for CAP evaluations by the school system. A test battery including seven CAP tests was used for this study: Binaural Fusion (BF) test, Masking Level Difference (MLD) test, Filtered Speech Test (FST), Time Compressed Sentence (TCS) test, Dichotic Digits Test (DDT), Staggered Spondaic Word (SSW) test, and Pitch Pattern Test (PPT). The subjects were given instruction prior to the test battery and administration of each test. For the purposes of this study, the sensitivity was determined by calculating the "hit rate" and the specificity was determined by calculating the "false positive rate". When the tests were all compared between the age groups, results showed: the BF, MLD, and FST were the three best tests that gave the best indications and results in the 7, 8, and 10 year old age groups. For the 9 year old group, the three best tests were PPT, BF, and DDT. For the 11 to 13 year old groups the best three tests were FST, TSC, and MLD. Based on these results, Singer and fellow investigators concluded that the three test battery of BF, FST, and MLD would be the best CAP for a high sensitivity (hit rate) and high specificity (low false positive). Although this test battery was concluded to be the best measure, it may not be the most cost effective with a total cost per subject of $317.69. Other cost and monetary values were not reported in this study.

Statement of Purpose

According to this research, filtered speech testing is a sensitive measure in it's ability to assess brainstem lesions, temporal lobe lesions, and individuals with (C)APD. However, there is no current test or research on Progressive Filtering. It is hypothesized that children with (C)APD will do significantly poorer on the Progressive Filtering screening tool compared to children with normal auditory processing skills.

CHAPTER III

PILOT STUDY

A pilot study was conducted prior to the development of the test stimuli to determine which filter frequencies should be included in the actual study. The following is a brief description of the Participants, Procedures, and Results from this pilot study. Detailed description of the Methods, Instrumentation, and Procedures can be found in Chapter IV of this document.

Participants

Prior to initiation of this study, the Institutional Review Board at Louisiana Tech University approved this project. The guardians of each participant signed a consent form and were allowed to ask any questions prior to data collection. Data were obtained from 11 participants who were divided into two groups: Experimental and Control. The Experimental Group consisted of eight children with a mean age of 9.25 (range 6 to 15 years) and the Control Group consisted of three children with a mean age of ten (range 9 to 11 years). Participants were recruited from the Louisiana Tech University Speech and Hearing Center and the surrounding parishes.

All participants had normal peripheral hearing as identified by pure-tone thresholds between 0-25 dB HL for octave frequencies between 500 Hz – 8000 Hz. In addition, normal middle ear functioning was present in all participants as determined by peak middle ear pressure of no less than -100 daPa and no greater than +25 daPa and static compliance measures of no less than .2 mmho, or patent pressure equalizing tubes (ASHA, 1997).

Participants in both groups received an initial (C)APD test battery to determine the presence or absence of a central auditory processing deficit. This battery included the *SSW*, *SCAN-C/A*, *Dichotic Digits*, and *Selective Auditory Attention Test*. For the purposes of this study, scores on the *SSW* and the *SCAN-C/A* tests were used to determine whether or not they qualified for the Experimental or Control Group. Participants were placed in the Experimental Group when scores were two or more standard deviations below the mean on two or more of the conditions on the *SSW* and/or *SCAN-C/A*. Participants in the Control Group were identified has having normal auditory function when no more than one condition on the *SSW* or *SCAN-C/A* were more than two standard deviations below the mean.

None of the participants had identifiable neurological disorders such as autism, handicapping conditions, or pervasive developmental delays as reported by their parents. Participants were not excluded based on the diagnosis of attention deficit disorder.

Instrumentation

Refer to Chapter IV for the instrumentation guidelines that were also used for the pilot study.

Procedure

All participants received the experimental test procedure (i.e., Progressive Filtering) (see Appendix A). The Progressive Filtering test consisted of 128 words randomly selected from the Northwestern University Auditory Test No.6 (NU-6). The NU-6 word lists were professionally recorded monosyllabic words and were purchased from Auditec of St. Louis. Each word list was copied to the Sony SoundForge 7.0 computer program and the carrier phrase "Say the word" removed leaving the monosyllabic word intact. Word lists 1A, 2A, 3A, and 4A were low pass filtered through the Adobe Audition 2.0 program at 4000, 2000, 1000, and 750 Hz with a rejection rate of 32 dB per octave. Words were randomly selected from the word lists and no words were repeated. The words were copied into one of the two channels in the SoundForge 7.0 program: channel one for the left ear and channel two for the right ear. The words were randomly placed in one of two channels ensuring that there were an equal number of words at each filtered frequency and an equal number of words presented to the right and left ears. There were 2 seconds between each word to ensure that the participant had enough time to repeat the words. After the filtering was completed, the lists were burned onto a compact disc (CD) for use on a computer. The Progressive Filtering Score sheet (see Appendix A) was used to record results.

The Progressive Filtered word list consisted of 128 words (64 in the right ear and 64 in the left ear) that were filtered at 4000, 2000, 1000, and 750 Hz. Each participant was given the following instructions:

> *"Repeat each word that you hear. The word may be hard to understand so guess if you are not sure what you heard. Do you have any questions?"*

Koss headphones were placed on each participants ears and the CD inserted into the CD player.

Results

The purpose of this pilot study was to determine whether or not there was a significant difference between the Experimental Group and Control Group performance on the same Progressive Filtered test. Scores for the *SCAN-C/A*, *SSW*, and Progressive Filtered test were calculated across each group (Control and Experimental). Mean data for the *SCAN-C/A, SSW*, and the Progressive Filtered word list test results are shown in Figures 5, 6, and 7.

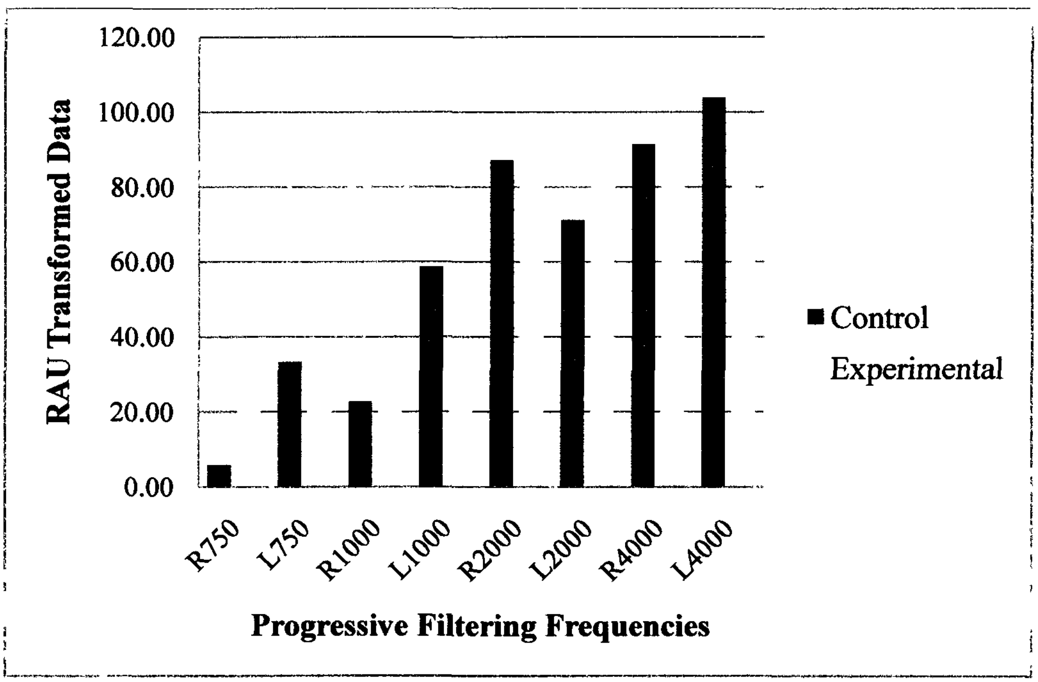

Figure 5. Mean Data for Progressive Filtering Word List Test Results for the Control and the Experimental Groups

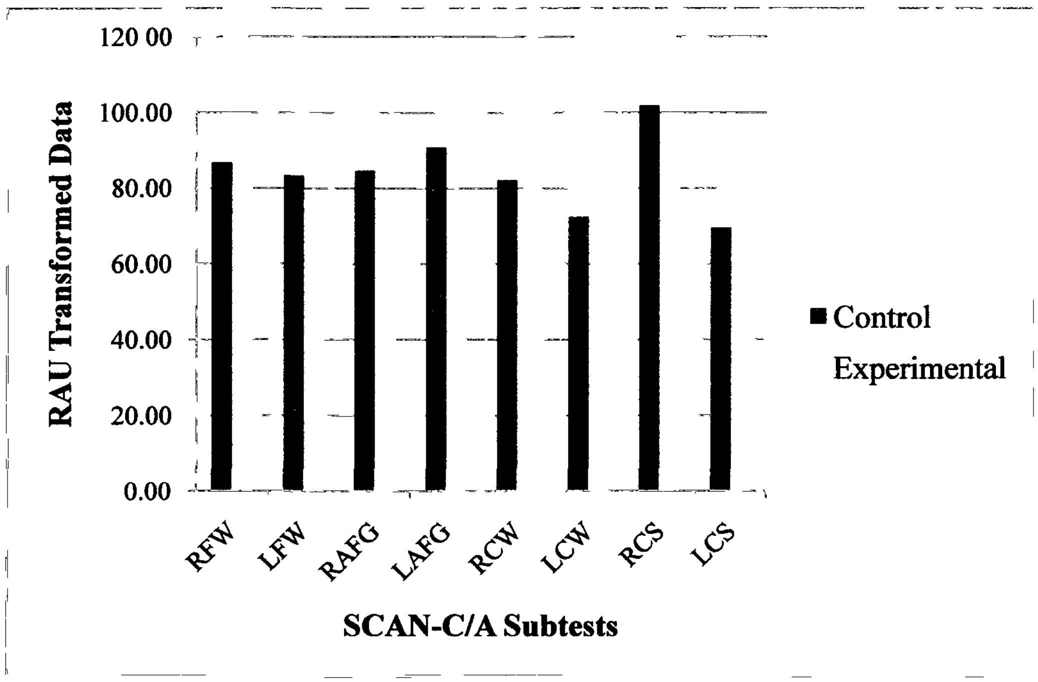

Figure 6. Mean Data of the *SCAN-C/A* Test Results for the Control and the Experimental Groups

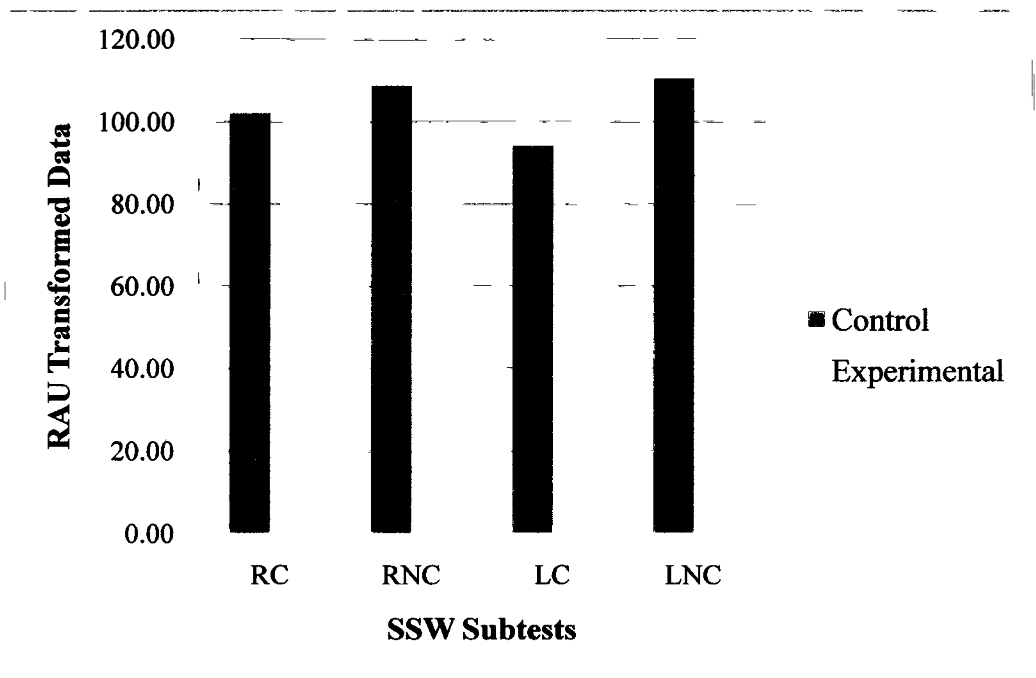

Figure 7. Mean Data of the *SSW* Test Results for the Control and Experimental Groups

An analysis of variance (ANOVA) with a Bonferroni correction was performed on the Progressive Filtering word list, *SCAN-C/A*, and *SSW* scores. All variables were transformed using the rationalized arcsine transform (RAU; Studebaker, 1985) to adjust for error variance when using percentages. The ranges of effect sizes were as follows: a large effect size was greater than or equal to .138, a medium effect size was greater than or equal to .059 to .137, and a small effect size was greater than or equal to .01 to .058 (Nolan & Heinzen, 2007). Between Subject Effects were determined for both groups on all three tests: Progressive Filtering, *SCAN-C*, and *SSW*. The Between Subject Effects of the Progressive Filtering word list are shown in Table 1.

Table 1.

Between Subject Effects of the Progressive Filtering Word List Scores

Group	F	Sig	Partial eta squared
R750	3.407	0.098	0.275 $^{\Delta}$
L750	1.278	0.288	0.124 ^{o}
R1000	2.772	0.130	0.236 $^{\Delta}$
L1000	1.526	0.248	0.145 $^{\Delta}$
R2000	0.004	0.949	0
L2000	1.317	0.281	0.128 ^{o}
R4000	0.003	0.961	0
L4000	0.395	0.545	0.042

Note. R = Right Ear
L = Left Ear
750,1000, 2000, 4000 = Filtered Frequency
Δ = Large Effect Size
o = Medium Effect Size
× = Small Effect Size
* = Significant at the .05 level

The analysis revealed no statistically significant group differences for any group variable; however, there were significant effect sizes noted for the R750 variable, F (1,10) = 3.407, p = 0.098, partial η^2 = 0.275; L750 variable F (1,10) = 1.278, p = 0.288, partial η^2 = 0.124; R1000 variable, F (1,10) = 2.772, p = 0.13, partial η^2 = 0.236; L1000 variable, F (1,10) = 1.526, p = 0.248, partial η^2 = 0.145; and L2000 variable, F (1,10) = 1.317, p = 0.281, partial η^2 = 0.128. There was no scientific or clinical significant difference for R2000 variable, F (1, 10) = 0.004, p = 0.949, partial η^2 = 0; R4000 variable, F (1, 10) = 0.003, p = 0.961, partial $\eta^2 = 0$; or L4000 variable, F (1,10) = 0.395, $p = 0.545$, partial $\eta^2 = 0.042$.

Table 2.

Between Subject Effects of the SCAN-C/A Scores

Group	F	Sig	Partial eta squared
RFW	0.372	0.557	0.400 Δ
LFW	0.414	0.536	0.044 ×
RAFG	1.172	0.307	0.115 o
LAFG	8.879	0.015*	0.497 Δ
RCW	0.660	0.438	0.068 o
LCW	2.595	0.142	0.224 Δ
RCS	0.591	0.462	0.062 o
LCS	0.075	0.790	0.008 ×

Note. R= Right Ear
L= Left Ear
FW= Filtered Words
AFG= Auditory Figure Ground
CW= Competing Words
CS= Competing Sentences
Δ = Large Effect Size
o = Medium Effect Size
× = Small Effect Size
* = Significant at the .05 level

The analysis revealed a significant group difference for LAFG variable, F (1, 10) = 8.879, $p = 0.015$, partial $\eta^2 = 0.497$. The analysis revealed no statistically significant group differences for any other group variable, however, there were significant effect sizes for the RFW variable, F (1,10) = 0.372, p = 0.557, partial η^2 = 0.4; LFW variable F (1,10) = 0.414, p = 0.536, partial η^2 = 0.044; RAFG variable, F (1,10) = 1.172, p = 0.307, partial η^2 = 0.115; RCW variable, F (1,10) = 0.66, p = 0.438, partial η^2 = 0.068; LCW variable, F (1,10) = 2.595, p = 0.142, partial η^2 = 0.224; RCS variable, F (1,10) = 0.591, p = 0.462, partial η^2 = 0.062; and LCS variable, F (1,10) = 0.075, p = 0.79, partial η^2 = 0.008.

Table 3.

Between Subject Effects of the SSW Scores

Group	F	Sig	Partial eta squared
RC	9.432	0.013*	0.512 $^{\Delta}$
RNC	12.302	0.007*	0.578 $^{\Delta}$
LC	6.109	0.035*	0.404 $^{\Delta}$
LNC	6.294	0.033*	0.412 $^{\Delta}$

Note. RC= Right Competing
RNC=Right Non-Competing
LC= Left Competing
LNC=Left Non-Competing
Δ = Large Effect Size
o = Medium Effect Size
× = Small Effect Size
* = Significant at the .05 level

The analysis revealed a significant effect sizes for RC variable, F (1, 10) = 9.432, p = 0.013, partial η^2 = 0.512; RNC variable, F (1,10) = 12.302, p = 0.007, partial η^2 = 0.578; LC variable, F (1,10) = 6.109, p = 0.035, partial η^2 = 0.404; and LNC variable, F (1,10) = 6.294, p = 0.033, partial η^2 = 0.412.

Conclusion

The results indicated that the *SCAN-C/A* and *SSW* did have clinical significance for group differences. The results also indicated that there was a clinical significant group difference between scores for the first three filtered frequencies (i.e. 750, 1000, and 2000 Hz). However, based on these results there was no clinical significant group difference at 4000 Hz filtered frequency. Therefore, based on the results of the pilot study, a filtered word list at 4000 Hz was not included in the test stimuli. Also, since the Progressive Filtered word lists were randomly selected from lists 1A, 2A, 3A and 4A of the NU-6 word lists, it was noted that the lists were no longer phonetically balanced when taken out of the original order. Therefore, in the newly formed word list for the current study, the word lists were presented in the original order to preserve the phonetically balanced characteristics of the word lists. In addition, a larger sample of participants was obtained in an attempt to identify statistically significant results.

CHAPTER IV

METHODS AND PROCEDURES

It is hypothesized that children with (C)APD will do significantly poorer on the Progressive Filtering screening tool compared to children with normal auditory processing skills. Therefore, the Progressive Filtering tool was designed to tax the auditory system in a specific manner by degrading the acoustic signal.

Participants

Prior to initiation of this study, the Institutional Review Board (IRB) at Louisiana Tech University approved this project. The guardians of each participant signed a consent form (see Appendix B) and were allowed to ask any questions prior to initiation of data collection. All participants were recruited from the Louisiana Tech University Speech and Hearing Center and the surrounding parishes. Twenty children, between the ages of 6 to 14 years, participated in this study. The participants were divided into two groups: Control and Experimental. The Control group consisted of 11 children with a mean age of 9.55 (range 6 to 14 years) who were identified as having normal auditory processing abilities. The Experimental group consisted of nine children with a mean age of 9.78 (range 7 to 13 years) who were identified as having a (C)APD.

All participants had normal peripheral hearing as identified by pure-tone thresholds between 0-25 dB HL for frequencies between 500 Hz – 8000 Hz. In addition, normal middle ear functioning was present in all participants as determined by peak middle ear pressure of no less than -100 daPa and no greater than +25 daPa with static compliance measures between .30 to 1.60 ml using a 226 Hz probe tone (Hall & Chandler, 1994). If auditory thresholds were poorer than 25 dB HL at any of the test frequencies and/or if tympanograms were abnormal, the participant was referred for further evaluation by an audiologist or physician and excluded from the study or deferred until normal audiological results were obtained.

Participants in the Experimental Group received an initial (C)APD test battery to determine whether they classified as having a (C)APD. The battery of testing for (C)APD included but was not limited to the *SSW*, *SCAN-C/A*, *Dichotic Digits*, and *Selective Auditory Attention Test*. For the purposes of this study, scores on the *SSW* and the *SCAN-C/A* tests were used to determine whether or not they qualified for the Experimental Group. Participants were placed in the Experimental Group when scores were two or more standard deviations below the mean on two or more of the conditions on the *SSW* and/or *SCAN-C/A*. Participants in the Control Group were identified as having normal auditory function on the *SSW* and the *SCAN-C/A*; that is, no more than one condition on the *SSW* or *SCAN-C/A* were more than two standard deviations below the mean.

None of the participants had identifiable neurological disorders such as autism, handicapping conditions, or pervasive developmental delays as reported by their parents. Participants were not excluded based on the diagnosis of attention deficit disorder.

Instrumentation

Otoscopy was performed using a Welch Allen otoscope. Middle ear functioning was assessed using a Grason-Stadler Tympstar Version 2 Middle Ear Analyzer (Med-Acoustics, Stone Mountain, GA) (ANSI S3.39, 1987, R2002). Pure-tone and speech testing was performed using a Grason-Stadler GSI-61 audiometer. The *SSW* and *SCAN-C/A* were delivered through the GSI-61 audiometer (Med-Acoustics, Stone Mountain, GA) (ANSI S3.6-1969, R-1973, R-2004) coupled to a Tascam CD-160 CD player. Each participant was administered the *SSW* and *SCAN-C/A* using standard procedures as described in the user manuals for each. EARTone 3A insert earphones (Med-Acoustics, Stone Mountain, GA) were also used for presentation of all audiometric testing. All equipment received annual electracoustical calibration and daily biological checks to ensure consistency of performance. All qualification and experimental testing were conducted in a sound-treated examination room (IAC, Model #404A; 2.7 x 2.5 meters) with ambient noise levels appropriate for testing unoccluded ears (ANSI S3.1-1991; American National Standards Institute, 1991).

The auditory processing tests that were used to test the auditory function of all participants consisted of two standardized tests: the *SCAN-C*: *A Test for Auditory Processing Disorders in Children – Revised* (has normative data for ages 6 to 11 years and 11 months) or the *SCAN-A*: *A Test for Auditory Processing Disorders in Adults – Revised* (has normative data for ages 12 years to adult), and the *Staggered Spondaic Word test (SSW)*.

The *SCAN-C* has four subtests: Filtered Words, Auditory Figure Ground, Competing Words, and Competing Sentences (Keith, 2000). The Filtered Words subtest measures the ability to understand a distorted speech signal. It consists of monosyllabic words that are low-pass filtered at 1000 Hz with a roll-off of 32 dB per octave. This subtest consists of 20 words that are presented to the right ear and 20 words that are presented to the left ear. The Auditory Figure Ground subtest measures the ability to comprehend speech in background noise. It consists of monosyllabic words that are recorded in the presence of a multitalker speech babble at a +8 signal-to-noise (SNR) ratio. This subtest has 20 words presented to the right ear and 20 words presented to the left ear. Both the Filtered Words and Auditory Figure Ground subtests are presented monaurally. The Competing Words subtest measures the ability to recognize a word when two speech signals are presented to both ears. The Competing Words subtest presents 15 monosyllabic word pairs in a directed right and directed left task. The participant is instructed to repeat both words heard. The Competing Sentences subtest measures the ability to repeat one of two sentences that are presented to both ears. The Competing Sentences subtest presents ten sentences to both ears simultaneously in a directed right and directed left ear task. The participant is directed to repeat the sentence in the designated ear and ignore the sentence in the other ear.

The *SCAN-A* has four subtests: Filtered Words, Auditory Figure-Ground, Competing Words, and Competing Sentences (Keith, 1987, 1994). Although similar to the *SCAN-C*, there are two subtest differences. Filtered Words have a low-pass filter of 750 Hz and Auditory Figure Ground has a SNR of +4 dB.

The *SSW* presents two spondaic words dichotically that are staggered in time (Katz, 1962, 1968). For example, the first syllable of the first spondee is presented in isolation to the right ear, the second syllable of the first spondee in the right ear overlaps with the first syllable of the spondee presented to the left ear, and the second syllable of the spondee delivered to the left ear is presented in isolation. The beginning ear order is alternated from right to left. The participant is required to repeat both spondees beginning with the presentation in the first ear; the presentation level is 50 dB SL above the pure-tone average. Four conditions (Right Non-Competing, Right Competing, Left Non-Competing, and Left Competing) provide the eight cardinal numbers necessary to score the *SSW*. The *SSW* provides a standardized measure of dichotic testing for individuals ages five through 69 years.

The investigator-designed Progressive Filtering screening tool consisted of 300 words selected from the Northwestern University Auditory Test No.6 (NU-6). The word lists were kept in their original form in order to preserve the phonetically balanced characteristic of the word lists. Professional recorded NU-6 word lists from Auditec of St. Louis were used to administer the stimuli. Each word lists were copied to the SoundForge 7.0 program and the carrier phrase "Say the word" was digitally removed leaving the monosyllabic word intact. Word lists 1A, 2A, 3A, and 4A were low-pass filtered through the Adobe Audition 2.0 program at 2000, 1000, or 750 Hz with a rejection rate of 32 dB per octave. Each word list consisted of 50 words and each participant received three word lists in the left ear and three in the right ear, totaling 300 words per participant. Each participant received a word list for each filtered frequency: 2000 Hz, 1000 Hz, and 750 Hz in each ear and the order of the word lists and filtered frequency were in a randomized order. A Progressive Filtering Score sheet (see Appendix C) was used to record results.

Procedure

Informed consent was received from the parents or guardians of all participants prior to the inclusion in the Progressive Filtering study. All participants received an audiological evaluation and a (Central) Auditory Processing Disorder test battery consisting minimally of the *SSW* and *SCAN-C/A*. All participants were then administered the Progressive Filtered word list. The list consisted of 300 words (150 in the right ear and 150 in the left ear) that were filtered at 2000, 1000, and 750 Hz. Each participant was given the following instructions for the Progressive Filtered word list:

> *"Repeat each word that you hear. The word may be hard to understand so guess if you are not sure what you heard. Do you have any questions?"*

The word lists were then delivered through the GSI 61 audiometer coupled to the Tascam CD-160 CD player. EARTone 3A insert earphones (Med-Acoustics, Stone Mountain, GA) were used for presentation of all audiometric testing.

CHAPTER V

RESULTS

The purpose of this study was to determine whether or not progressive filtering could be used to differentially diagnose those with (C)APD from those without this disorder. The data from the pilot study indicated that there was no clinically significant difference between groups at 4000 Hz; therefore, 4000 Hz was not included in the Progressive Filtered word lists in this current study. This study included a total of 20 participants with 11 participants in the control group with a mean age of 9.55 (range 6 to 14 years), and nine participants in the Experimental group with a mean age of 9.78 (range 7 to 13 years) who were identified as having a (C)APD. All participants were given the auditory processing test battery (i.e. the *SSW* and *SCAN-C/A* tests) and the Progressive Filtered screening tool. Scores for the *SCAN-C/A*, *SSW*, and Progressive Filtered screening tool were calculated across each group (Control and Experimental).

Prior to the analysis, each test protocol was examined for correct scoring by the principle investigator and the mentoring professor. Of the 18 individual data points for 21 participants (18 x 20 = 360), one variable was miscalculated out of the possible 360 resulting in 99% inter-test reliability. Corrections were made, and each variable was examined in SPSS, 2008, v. 17 to evaluate the accuracy of data entry, skewness, and kurtosis. Percentages were calculated for each raw score. Skewness for the raw variables were as follows: mild – 10% (i.e. 1 SD below the mean), moderate – 12% (i.e., 2 SDs below the mean), and severe - .01% (i.e., 3 SDs below the mean). Kurtosis for the raw variables was as follows: mild – 2% (i.e. 1 SD below the mean), moderate – 9% (i.e., 2 SDs below the mean), and severe 4% (i.e., 3 SDs below the mean). To reduce severe skewness and kurtosis, all variables were transformed using the rationalized arcsine transform (RAU; Studebaker, 1985) to adjust for error variance when using percentages. All variables were re-evaluated for skewness and kurtosis. After transformation, only .11% of the variables were mildly skewed (i.e. 1 SD below the mean) and .11% of the transformed variables had moderate kurtosis (i.e., 2 SDs below the mean). George and Mallery (2008) report the skewness and kurtosis of ± 2.0 are within acceptable limits; therefore, no additional transformations were performed.

Statistical Analysis

A one way analysis of variance (ANOVA) with a Bonferroni correction was performed for the Progressive Filtering Screening Tool dependent variables (R750, L750, R1000, L1000, R2000, and L2000) for the two groups. The between subject variables were the control and experimental groups and the independent variable was the Progressive Filtering test stimulus. Both Levene's Test of Equality of Variances and Box's Test of Equality of Covariance Matrices were not significant for any these of variables suggesting homogeneity.

Table 4.

RAU Means, Standard Deviations, and Confidence Intervals for Progressive Filtering

Variable	Group	Mean	Std. Deviation	95% Confidence interval for mean	
				Lower bound	Upper bound
R750	Control	22.89	8.57	17.14	28.65
	Experimental	12.92	9.75	5.42	20.41
L750	Control	19.66	8.09	14.23	25.10
	Experimental	10.32	9.16	3.28	17.36
R1000	Control	42.40	8.86	36.44	48.35
	Experimental	30.45	14.57	19.25	41.66
L1000	Control	39.78	10.56	32.68	46.87
	Experimental	29.00	17.30	15.70	42.29
R2000	Control	89.89	9.80	83.31	96.48
	Experimental	86.15	9.46	78.88	93.42
L2000	Control	89.21	9.35	82.92	95.49
	Experimental	81.38	7.04	75.97	86.79

Table 5.

Between Subject Effects of the Progressive Filtering Word List

Group	F	Sig	Partial Eta Squared
R750	5.939	0.025*	0.248 Δ
L750	5.875	0.026*	0.246 Δ
R1000	5.115	0.036*	0.221 Δ
L1000	2.950	0.103	0.141 Δ
R2000	0.746	0.399	0.040 ×
L2000	4.291	0.053	0.193 Δ

Note. R= Right Ear
L= Left Ear
750,1000, 2000 = Filtered Frequency
Δ = Large Effect Size
o = Medium Effect Size
× = Small Effect Size
* = Significant at the .05 level

Using a Bonferroni correction, the analysis revealed statistically significant group differences for R750, F (1, 19) = 5.939, p = 0.025, partial η^2 = 0.248; L750, F (1,19) = 5.875, p = 0.026, partial η^2 = 0.24; and R1000, F (1,19) = 5.115, p = 0.036, partial η^2 = 0.221. There was no statistically significant group differences for L1000, F (1, 19) = 2.950, p = 0.103, partial η^2 = 0.141; R2000, F (1,19) = 0.746, p = 0.399, partial η^2 = 0.040; and L2000, F (1,19) = 4.291, p = 0.053, partial η^2 = 0.193.

The ranges of effect sizes were determined as follows: a large effect size was greater than or equal to .138, a medium effect size was greater than or equal to .059 to .137, and a small effect size was greater than or equal to .01 to .058 (Nolan & Heinzen, 2007). The analysis revealed a large effect size for R750, L750, R1000, L1000, and L2000; and a small effect size for R2000.

CHAPTER VI

DISCUSSION

The overall findings of the current investigation supported the hypothesis that the investigator-designed Progressive Filtering screening tool can be used to differentiate individuals with a (C)APD from individuals without this disorder. Not only did this study identify statistically significant differences between these two groups but clinically relevant differences between frequencies as well. Statistically significant differences between group performances were noted on the R750, L750, and R1000 filtered frequencies. Although not statistically different, a large effect size was noted on R750, L750, R1000, L1000, and L2000; and a small effect size on R2000 filtered frequency showing clinical significance on all filtered frequencies. These differentiated measures were identified on the investigator-designed Progressive Filtering word lists and standardized measures of auditory processing abilities (i.e., *SCAN-C/A, SSW*).

Two findings emerged as a result of this test procedure. First, the children with a diagnosis of (C)APD had a statistically significant differences in performance when compared to the group without (C)APD on the progressively filtering word list. That is, the Progressive Filtering screening tool was sensitive enough to detect a difference between children with (C)APD and with normal auditory processing abilities for some frequencies. While there were not statistically significant differences for the L1000, L2000, and R2000 filtered frequencies, these conditions did yield effect sizes showing clinically significant differences. This research supports the research of (Ferre & Wilber, 1986) in that as the filtered frequency increased, the stimulus decreased in its ability to tax the auditory system. In summary, clinical significance was shown on all filtered frequencies within the Progressive Filtering Screening tool.

The results of this study should be viewed cautiously due to the small sample size and additional research should be conducted to include a larger sample size to in order to generalize to a larger population. Also, age specific normative data should be collected on normal populations to assess the impact of auditory maturation. As more research is conducted on possible screening tools of (C)APD, we come closer in fact to developing a possible gold standard for testing (C)APD. Future studies related to Progressive Filtering should include not only a shorter screening tool, but also a remediation or training tool utilizing the Progressive Filtering process.

The Progressive Filtered screening tool was shown to differentiate between those children with a (C)APD and those without this disorder when the stimulus was made sufficiently difficult (i.e., filtered at lower frequency levels). As mentioned earlier, there is still a need for a 'gold standard' test battery for (C)APD (Schow & Chermak, 1999). It has been determined that filtered speech is an important area of research because of its ability to differentiate between subjects with temporal lobe lesions (Bocca, 1955, 1958; Jerger, 1960), brainstem lesions (Stephens & Thornton, 1976), and subjects with auditory processing difficulties (Keith & Jerger, 1991; Keith, 1999, 2000; Musiek & Geurkink, 1980; Rintelman, 1985). While more research should be conducted on (C)APD and a proper gold standard, the Progressive Filtering screening tool has promising capabilities to differentiate between subjects with and without (C)APD. With additional research, this screening tool could possibly be used as a unitary test of (C)APD or in conjunction with other auditory processing tests as part of a test battery.

APPENDIX A

EXPERIMENTAL TEST PROCEDURE SCORESHEET

	RIGHT	LEFT	R 750	L 750	R 1000	L 1000	R 2000	L 2000	R 4000	L 4000
1	3A – LID									
2		2A – CHAIR								
3		4A – DOG								
4		4A - CHAIN								
5		2A - WHITE								
6	3A – MESS									
7	4A - FOOD									
8	4A - KICK									
9		4A - SAIL								
10		3A – SOUP								
11	4A - RIPE									
12		3A – HIRE								
13	2A – CHIEF									
14	1A – SHOUT									
15	3A – DATE									
16		4A – WHEAT								
17	2A – JUICE									
18		4A – NEAT								
19		3A – LATE								
20		1A - POOL								
21	4A - MOOD									
22	2A – CALM									
23		4A – JOIN								
24		2A - VOICE								
25	1A – DEATH									
26	2A – TURN									
27	4A – VOTE									
28		1A - PAGE								
29		2A – GAZE								
30	1A – WHIP									
31	4A – SOUR									
32		3A – POLE								
33	3A – HIT									
34	2A – THOUGHT									
35		4A - PEG								
36		1A – YES								
37		1A – THIRD								
38	1A – JAR									
39	3A – BEG									
40		1A – RAID								
41		4A - BATH								
42	2A – YOUNG									
43	3A - MOUSE									
44		3A – PAIN								
45	1A – NAG									
46		2A – TON								
47		3A - WHEN								
48	1A – TIP									
49	1A - GOOSE									
50	1A – KITE									
51		4A - THUMB								
52		4A – LONG								
53		4A - CHECK								
54	3A – PHONE									
55	3A - NAME									
56		2A - LOAF								
57	3A – FIVE									
58		4A - CAME								
59		3A – RAT								
60		3A – TELL								
61		3A - ROAD								
62	3A – BAR									
63	1A – SELL									
64	1A – FALL									
65		4A- PERCH								

66		4A - DOLL								
67	3A – SEARCH									
68	2A - WITCH									
69		3A - HALF								
70		3A - LUCK								
71		2A - LIVE								
72	3A – GOOD									
73	2A – HATE									
74	2A – FAR									
75		1A - BURN								
76		1A - RAG								
77		1A – VINE								
78		1A - TAKE								
79	2A – DIME									
80	2A – DEAD									
81		2A - MERGE								
82		1A - CHOICE								
83		1A - WEEK								
84		2A - DEEP								
85	1A - MODE									
86	2A- SHACK									
87	3A – WALK									
88	3A - SHALL									
89		4A - JUDGE								
90	2A – NUMB									
91		2A - RAIN								
92	4A – TIRE									
93		3A - YOUTH								
94	3A – CHAT									
95		1A - SUB								
96		1A – PUFF								
97	1A – LOT									
98	1A – MOON									
99		3A - NOTE								
100		2A – ROT								
101	1A - KNOCK									
102		4A – SHOULD								
103	3A - SHEEP									
104	4A – HALL									
105		3A – THIN								
106	4A – RED									
107	1A – SURE									
108	1A – KING									
109		2A - WAG								
110	4A – WIFE									
111	4A – TIME									
112		4A - LOSE								
113		2A – KEG								
114		2A - READ								
115		1A – LOVE								
116	1A – GAP									
117	4A – FIT									
118		4A – ROSE								
119		3A - BASE								
120	1A – TOUGH									
121	2A – BITE									
122		1A - JAIL								
123		2A - PAD								
124	3A – WIRE									
125	4A – TAPE									
126		3A - TALK								
127	2A- MATCH									
128	2A - LEARN									

APPENDIX B

APPROVALS

HUMAN SUBJECTS CONSENT FORM

Pre-test Only

The following is a brief summary of the project in which you have been asked to participate. Please read this information before signing below:

TITLE: Progressive Filtering Training

PURPOSE OF STUDY/PROJECT: The purpose of this project is to develop a new therapeutic tool for the treatment of children identified as having a central auditory processing disorder.

PROCEDURE: Prior to inclusion in this study, each child will receive a standard audiometric battery (otoscopic examination, tympanometry, acoustic reflexes, pure tone testing, speech reception threshold, word recognition testing), the *Staggered Spondaic Word* test, *SCAN-C: Test for Auditory Processing Disorders in Children-Revised (or SCAN-A), the Time Compressed Sentence test,* and a baseline Progressive Filtering Training.

INSTRUMENTS: The participant's identity will not be used in any form in the analysis or representation of the data. Only numerical data such as percent correct will be used in the presentation of the results.

RISKS/ALTERNATIVE TREATMENTS: There are no known risks to subjects. These procedures do not vary from routine audiometric measures. The experimental aspect of this study is filtering words. Participation is voluntary with parental consent. The participant understands that Louisiana Tech is not able to offer financial compensation nor to absorb the costs of medical treatment should you be injured as a result of participating in this research.

BENEFITS/COMPENSATION: None.

I,______________________________, attest with my signature that I have read and understood the following description of the study, "Progressive Filtering Training", and its purposes and methods. I understand that my and my child's participation in this research is strictly voluntary and my participation or refusal to participate in this study will not affect my relationship with Louisiana Tech University and the Louisiana Tech University Speech and Hearing Center. Further, I understand that I may withdraw my child at any time or refuse to answer any questions without penalty. Upon completion of the study, I understand that the results will be freely available to me upon request. I understand that the results will be confidential, accessible only to the project director, principal experimenters, myself, or a legally appointed representative. I have not been requested to waive nor do I waive any of my rights related to participating in this study.

I hereby give my permission for my child, ___________________________, to participate in the above mentioned study.

____ ___________________________

Signature of Participant or Guardian Date

CONTACT INFORMATION: The principal experimenter listed below may be reached to answer questions about the research, participant's rights, or related matters.

Sheryl S. Shoemaker, Au.D. Department of Speech (318) 257-4764
Sarah M. Johnson, B.S. Student (318) 446-3183

Members of the Human Use Committee of Louisiana Tech University may also be contacted if a problem cannot be discussed with the experimenters:

Dr. Les Guice (257-3056)
Dr. Mary Livingston (257-2292 or 257-4315)

LOUISIANA TECH
UNIVERSITY

OFFICE OF UNIVERSITY RESEARCH

MEMORANDUM

TO: Dr. Sheryl Shoemaker, and Ms. Sarah Johnson

FROM: Barbara Talbot, University Research

SUBJECT: Human Use Committee Review

DATE: September 29, 2010

RE: Approved Continuation of Study HUC 627

TITLE: **"Progressive Filtering Training"**

HUC- 627 Renewal

The above referenced study has been approved as of September 29, 2010 as a continuation of the original study that received approval on September 29, 2009. **This project will need to receive a continuation review by the IRB if the project, including collecting or analyzing data, continues beyond September 29, 2011.** Any discrepancies in procedure or changes that have been made including approved changes should be noted in the review application. Projects involving NIH funds require annual education training to be documented. For more information regarding this, contact the Office of University Research.

You are requested to maintain written records of your procedures, data collected, and subjects involved. These records will need to be available upon request during the conduct of the study and retained by the university for three years after the conclusion of the study. If changes occur in recruiting of subjects, informed consent process or in your research protocol, or if unanticipated problems should arise it is the Researchers responsibility to notify the Office of Research or IRB in writing. The project should be discontinued until modifications can be reviewed and approved.

If you have any questions, please contact Dr. Mary Livingston at 257-4315.

A MEMBER OF THE UNIVERSITY OF LOUISIANA SYSTEM

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APPENDIX C

PROGRESSIVE FILTERING SCORESHEET

SUBJECT: 1 **DOB/AGE:**

DATE:

FILTERING SEQUENCE:

1A/2A	**750 HZ**
1B/2B	**1000 HZ**
1C/2C	**2000 HZ**

750 HZ				**1000 HZ**			
1A - RIGHT		**2A – LEFT**		**1B – RIGHT**		**2B – LEFT**	
LAUD	LOVE	PICK	MILL	BURN	SIZE	LIVE	HUSH
BOAT	SURE	ROOM	HUSH	LOT	POOL	VOICE	DEAD
POOL	KNOCK	NICE	SHACK	SUB	VINE	TON	PAD
NAG	CHOICE	SAID	READ	HOME	CHALK	LEARN	DEAD
LIMB	HASH	FAIL	ROT	DIME	LAUD	MATCH	MERGE
SHOUT	LOT	SOUTH	HATE	WHICH	GOOSE	CHAIR	JUICE
SUB	RAID	WHITE	LIVE	KEEN	SHOUT	DEEP	KEG
VINE	HURL	KEEP	BOOK	YES	FAT	PIKE	GIN
DIME	MOON	DEAD	VOICE	BOAT	PUFF	ROOM	NICE
GOOSE	PAGE	LOAF	GAZE	SURE	JAR	READ	NUMB
WHIP	YES	DAB	PAD	HURL	REACH	CALM	CHIEF
TOUGH	REACH	NUMB	THOUGHT	DOOR	RAG	BOOK	GAZE
PUFF	KING	JUICE	BOUGHT	KITE	MODE	DAB	YOUNG
KEEN	HOME	CHIEF	TURN	SELL	TIP	LOAF	KEEP
DEATH	RAG	MERGE	CHAIR	NAG	PAGE	GOAL	TOOL
SELL	WHICH	WAG	LORE	TAKE	RAID	SHACK	SOAP
TAKE	WEEK	RAIN	BITE	FALL	RAISE	FAR	HATE
FALL	SIZE	WITCH	HAZE	WEEK	BEAN	WITCH	TURN
RAISE	MODE	SOAP	MATCH	DEATH	HASH	ROT	RAIN
THIRD	BEAN	YOUNG	LEARN	LOVE	LIMB	PICK	SHAWL
GAP	TIP	TON	SHAWL	TOUGH	THIRD	FAIL	BOUGHT
FAT	CHALK	KEG	DEEP	GAP	JAIL	SAID	THOUGH
MET	JAIL	CALM	GIN	MOON	KNOCK	WAG	BITE
JAR	BURN	TOOL	GOAL	CHOICE	WHIP	HAZE	LORE
DOOR	KITE	PIKE	FAR	KING	MET	WHITE	SOUTH

2000 HZ

1C – RIGHT		2C – LEFT	
RAISE	FAIL	DEAD	SOUTH
DOOR	VINE	JUICE	MILL
TIP	JAIL	MERGE	WHICH
SURE	HOME	YOUNG	TOOL
HURL	BOAT	CALM	NUMB
MET	MODE	BITE	HAZE
BURN	TOUGH	RAIN	PICK
SELL	LOT	MATCH	TURN
REACH	RAID	BOOK	GOAL
DIME	TAKE	LOAF	VOICE
JAR	PAGE	NICE	KEEP
DEATH	KEEN	BOUGHT	THOUGHT
WHICH	LAUD	TON	FAR
THIRD	LIMB	SHAWL	READ
POOL	GOOSE	WHITE	HUSH
MOON	GAP	HATE	CHAIR
FAT	SUB	SHACK	CHIEF
KING	NAGE	PIKE	KEG
CHALK	SIZE	FAIL	SOAP
YES	HASH	ROT	SAID
WEEK	LOVE	GIN	DAB
WHIP	KNOCK	PAD	WAG
BEAN	PUFF	GAZE	DEEP
CHOICE	SHOUT	LIVE	LEARN
RAG	KITE	ROOM	LORE

APPENDIX D

LOUISIANA TECH SPEECH AND HEARING CENTER AUDIOGRAM

LOUISIANA TECH UNIVERSITY
SPEECH AND HEARING CENTER
RUSTON, LOUISIANA

P.O. Box 3165, Ruston, LA 71272 Phone: (318) 257-4764 Fax: (318) 257-4492

Name: ______________________ DOB: ____________ Gender: ___ Date: _______

Center File #: ______________________ Audiometer: ________ Reliability: ___________

Pure Tone Audiometry (Re: ANSI 1996)

FREQUENCY IN HERTZ

HEARING LEVEL IN DECIBELS (dB)	250	500	1000	2000	4000	8000
0						
10						
20						
30						
40						
50						
60						
70						
80						
90						
100						
110						
120						

MASKING

	R	L	R	L	R	L	R	L	R	L	R	L	
AC													AC
BC													BC

Speech Audiometry

	Speech material	RIGHT	LEFT	BIN	AIDED	UNAID
SRT						
SDT						
PTA __						
MCL						
UCL						
Masking						

dB__	Speech material	RIGHT	LEFT	BIN	AID	UNAID
		%	%	%	%	%
		%	%	%	%	%
		%	%	%	%	%
Masking						

KEY

L	STIMULUS	R
X	AC	O
□	AC Mask	Δ
>	BC	<
]	BC Mask	[
↓	No Resp	↓
L	Aided SF	R
	SF	S

TEST TYPE	TRANSDUCER
Standard	Insert
Play	Circumaural
COR/VRA	Sound Field
BOA	

Acoustic Reflex Thresholds

Probe	Stim	500	1000	2000	4000
R	R				
R	L				
L	L				
L	R				
Reflex	Decay	500	1000		
R	L				
L	R				

Tympanometry

	R	L
Tymp Type		
Peak Pressure		
Gradient		
Static Compl		
Base Volume		

Otoacoustic Emissions (OAEs)

EMISSION TYPE USED	TEST TYPE PERFORMED
Transient	OAE Diagnostic
Distortion Product	OAE Screen
OAE RESULTS SHOWED THE	FOLLOWING:
Right Ear	
Left Ear	

Hearing Aid Information

Right Ear ______________________

Left Ear ______________________

Otoscopy ______________________

Comments ______________________

Student Clinician ______________________

Clinical Educator ______________________

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