TOWSON UNIVERSITY
OFFICE OF GRADUATE STUDIES

THE EFFECTS OF ACOUSTICALLY MODIFIED SPEECH TESTS ON THE SPEECH PERCEPTION ABILITIES OF INDIVIDUALS WITH SENSORINEURAL HEARING LOSS

by

Cortney A. Butler

A Doctoral Thesis

Presented to the faculty of

Towson University

in partial fulfillment

of the requirements for the degree

Doctor of Audiology

Towson University
Towson, Maryland 21252

May 2014

OFFICE OF GRADUATE STUDIES

AUDIOLOGY DOCTORAL THESIS APPROVAL PAGE

This is to certify that the Audiology Doctoral Thesis prepared by Cortney Butler entitled: The Effects of Acoustically Modified Speech Tests on the Speech Perception Abilities of Individuals with Sensorineural Hearing Loss has been approved by her committee as satisfactory completion of the Audiology Doctoral Thesis requirement for the degree, Doctor of Audiology (Au.D.).

Brian M Kreisman

Brian Kreisman, Ph.D.
Chair, Audiology Doctoral Thesis Committee

4/29/13
Date

Andrew John, Ph.D.
Committee Member

April 29, 2013
Date

Stephen Pallett, Au.D.
Co-Chair, Committee Member

4/29/13
Date

Janet V DeLany
Graduate Dean

May 11, 2013
Date

ACKNOWLEDGEMENTS

I would like to say a special thank you to my thesis chair, Dr. Brian Kreisman, as well as my thesis committee members, Dr. Stephen Pallett and Dr. Andrew John, for taking part in this project and for guiding me and supporting me through it. What seemed like such a daunting task at the beginning became an integral part of my experience in the doctor of audiology program. I am thankful to my thesis committee for their guidance and encouragement. I would also like to thank my family and friends for their love and support through this process. Last, I would like to provide a special thank you to my mother and to my daughter, my two biggest fans.

ABSTRACT

THE EFFECTS OF ACOUSTICALLY MODIFIED SPEECH TESTS ON THE SPEECH PERCEPTION ABILITIES OF INDIVIDUALS WITH SENSORINEURAL HEARING LOSS

Cortney A. Butler

Audiologists determine the maximum speech perception abilities of individuals with hearing loss in order to accurately evaluate speech understanding and estimate communication impairment, assess the need for amplification, authenticate hearing aid benefit, and provide audiologic rehabilitation and counseling. In the current study, word and sentence tests were acoustically-modified to see if individuals with flat or sloping mild to moderately-severe SNHL performed better in the modified conditions versus the unmodified condition. Mid- and high-frequency energy was added into NU-6 word lists and HINT sentence lists using three different filter conditions (2 dB/octave, 5 dB/octave, and 8 dB/octave) and a cutoff frequency of 1000 Hz to account for the USOM by low frequency speech sounds. Results from 28 participants revealed statistically-significant improvements in WRS and RTS scores between the unmodified NU-6 and HINT lists to the acoustically-modified lists. It was determined that the acoustically-modified speech stimuli provided additional mid- to high-frequency energy and therefore reduced the

USOM, which allows for the most accurate measurement of speech perception abilities and prediction of aided benefit for individuals with SNHL.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

When one thinks of an audiologist, they most likely think of hearing and the ears. Most individuals communicate via hearing and speech; therefore, for those people the ability to hear and to understand speech is an integral part of life. One important part of what an audiologist does is assessing speech understanding. Such assessments are especially important for individuals with sensorineural hearing loss (SNHL). Not only is the audibility of sound affected with SNHL, but the clarity of speech is often affected (ASHA, 2008; Gelfand, 2001; Plomp, 1978). Pure-tone thresholds obtained during audiologic evaluations do not always accurately predict speech understanding abilities (Crandell, 1991; Killion, 2002; Preminger & Wiley, 1985). Part of the audiologic test battery includes speech audiometry, which allows the audiologist to determine an individual's ability to understand and perceive speech by obtaining a word recognition score (WRS). Speech audiometry was developed between the 1920s and 1930s from work conducted at Bell Labs, in which the efficiency of communication systems was being analyzed (Hawley, 1995). It wasn't until after World War II, though, that there was a push for speech perception testing because veterans began to return from war with hearing loss (Hawley, 1995; Schoepflin, 2012).

The WRS is a measure that estimates the speech understanding and consequently communicative ability of an individual. The WRS is also used to assess whether or not a more exhaustive diagnostic assessment should be completed due to possible pathological ear disorders. Last, the WRS is a useful tool for determining hearing aid need and also for validating the effectiveness of hearing aids with patients (Dubno, Lee, Klein, Matthews, & Lam, 1995; Gelfand, 2001; McArdle & Hnath-Chisolm, 2009; Schoepflin, 2012). To date, there has not been a standardized protocol for word recognition testing approved for audiologists. It is likely for this reason that much debate still exists and research is ongoing to find the most accurate method for obtaining a WRS (Guthrie & Mackersie, 2009; Wiley, Stoppenbach, Feldhake, Moss, & Thordardottir, 1995).

The most common clinically used presentation level for WRS is at a fixed sensation level (SL) above the speech recognition threshold (SRT) (Gelfand, 2001; Martin & Morris, 1989). This level is typically at average conversational speech for individuals with normal hearing, and is at a level that all sounds should be audible for individuals with hearing loss so that the WRS is obtained at their maximum performance level (Guthrie & Mackersie, 2009). Unfortunately, utilizing an "optimal" presentation level may not yield an accurate WRS. As discussed later in this paper, there are many assessment factors and patient factors that can negatively affect an individual's WRS (Crandell, 1991; McArdle & Hnath-Chisolm, 2009; Wiley et al., 1995); certain factors can be controlled by the audiologist.

Among these factors that can affect the WRS is one that cannot be confidently controlled by the clinician, non-clinical masking. When amplified low-frequency sounds cover up high-frequency sounds, this is known as the upward spread of masking (USOM). An adequately intense low-frequency sound (masker) can extend to higher frequencies and mask out those high frequencies; however, the low frequency sounds will not mask lower frequencies. This is the USOM, and it is due to the tonotopic organization within the cochlea (Gagne, 1988; Gelfand, 2001; Wegel & Lane, 1924). Noise reduction algorithms are available in today's hearing aids to reduce low-frequency noise; and therefore, to reduce USOM caused by an external noise source (Cook, Bacon, & Sammeth, 1997; Vickers, Moore, & Baer, 2001). However, there has not been much research on USOM due to amplified low-frequency speech and how this may affect individual's speech understanding abilities in certain situations. For example, individuals with predominantly high-frequency hearing loss may wear hearing aids to increase the volume of sounds coming in, but depending on how the hearing aids are set, they may be over amplifying some of the softer low-frequency parts of speech. It is customary for audiologists to present speech stimuli at a fixed level above the patient's SRT when obtaining the WRS in order for the speech to be audible and comfortable for the patient to repeat back. For individuals with sloping SNHL, the mid- and high- frequency parts of speech become audible while the low-frequency sounds are possibly over amplified. This increase in amplified low-frequency speech may result in USOM, and consequently, a decrease in the WRS.

In order to obtain a more accurate maximum WRS, additional energy could be applied to the mid- and high-frequency regions of speech in order to control for the USOM by low-frequency speech energy. The purpose of this study was to do just that by acoustically modifying word and sentence lists by providing additional energy in the mid- to high-frequency regions, and to examine the effects of the modified word and sentence tests to see if the USOM could be controlled and if speech perception abilities would improve in individuals with a mild to moderately-severe degree of SNHL.

CHAPTER 2

REVIEW OF LITERATURE

Effects of Sensorineural Hearing Loss on Speech Understanding

Of the different types of hearing loss, SNHL is the most common (ASHA, 2011) and is typically the type of hearing loss treated clinically with hearing aids. Individuals with SNHL have damage to the hair cells in the cochlea of the inner ear and/or to the nerve pathways that branch from the inner ear to the brain (Gelfand, 2001; Moore, 1998). Sensorineural hearing loss affects the audibility of sounds and also the clarity of sounds (Gelfand, 2001; McArdle & Hnath-Chisolm, 2009; Moore, 1998). The degree of SNHL as well as the configuration of the hearing loss can vary greatly among individuals. One may have low-frequency hearing loss where the low-frequency tones are more difficult to hear than the mid- to high- frequency tones, or high-frequency hearing loss where the high-frequency tones are affected more. A flat hearing loss is where the degree of loss is very similar from the low to the high frequencies. Sensorineural hearing loss can range in severity from slight to profound (ASHA, 2011).

A common audiogram configuration for individuals with SNHL reveals mid- to high-frequency sloping hearing loss. Often, the low-frequency hearing sensitivity is preserved while mid- to high-frequency hearing sensitivity is reduced. This is the typical audiogram configuration accompanying age-related auditory impairment, which is known as presbycusis (CHABA, 1988). Although the pure tone audiogram is useful in that it quantifies the degree of hearing loss at certain important frequencies (Silverman & Hirsh, 1955), an individual's speech understanding abilities cannot always be predicted by looking at the pure tone thresholds (Crandell, 1991; McArdle & Hnath-Chisolm, 2009, Preminger & Wiley, 1985). Likewise, the pure tone audiogram will not consistently predict an individual's speech recognition performance in noise (Killion, 2002).

In fact, a common concern in the field of audiology is how accurately an individual's speech perception abilities can be estimated. Two people with the same degree and configuration of hearing loss may have very different word recognition and discrimination abilities (Crandell, 1991; Preminger & Wiley, 1985). Many patients with auditory deficits have trouble with speech intelligibility, and more importantly with communication. It is for this reason that speech perception testing is an essential part of the basic comprehensive audiologic evaluation (ASHA, 2006).

The comprehensive audiologic test battery includes speech audiometry, which typically consists of two parts. A speech recognition threshold (SRT) is obtained first, in which the audiologist presents words at increasingly softer levels to find the lowest level (in decibels hearing level [dB HL]) that an individual can repeat the words back at least 50% of the time (ASHA, 1988). The speech stimuli are spondaic words, which are two-syllable words that contain equal emphasis on the first and second syllables (ASHA, 1988; Gelfand, 2001). Obtaining the SRT allows the audiologist to determine if the patient has decreased audibility or sensitivity to sound and also to verify that the pure tone thresholds agree with the SRT (McArdle & Hnath-Chisolm, 2009).

A supra-threshold measure, the WRS, is normally acquired after the SRT. Monosyllabic (one syllable) words are presented at a specific level referenced to the SRT or the pure tone average (PTA); the PTA is the average of the pure tone thresholds obtained at 500, 1000, and 2000 Hz (Gelfand, 2001). This exact level above the SRT or the PTA is in decibels sensation level (dB SL). For example, if an SRT of 25 dB HL was obtained and the WRS was to be acquired at 40 dB SL re: the SRT; monosyllabic words would be presented to the individual at 65 dB HL (40 dB above the SRT). This measure allows the clinician to evaluate if an individual has decreased clarity or distortion of sounds by obtaining a percent correct score (Gelfand, 2001; McArdle & Hnath-Chisolm, 2009). Audiologists obtain a WRS to determine an individual's maximum speech understanding in an ideal listening environment (Dirks, Kamm, Bower, & Betsworth, 1977; Gelfand, 2001; McArdle & Hnath-Chisolm, 2009).

Word Recognition Testing

The WRS has many clinical applications such as: evaluation of speech understanding and estimating communication impairment, providing an additional test measure to aid in pathological ear disorder diagnosis, assessing the need for amplification, authenticating hearing aid benefit, and audiologic rehabilitation and counseling (Dubno et al., 1995; Gelfand, 2001; McArdle & Hnath-Chisolm, 2009). Speech intelligibility scores are important for making many decisions regarding a patient's auditory functioning. The WRS is typically obtained at an intensity level that is intended to achieve the individual's maximum recognition ability (commonly abbreviated PB_{max}). This intensity level can be the most comfortable listening level (MCL) or it can be at a predetermined sensation level relative to the SRT or pure tone average (PTA) (Gelfand, 2001). To obtain PB_{max}, the audiologist must complete a performance intensity (PI) function by obtaining WRS at multiple intensities to determine the maximum score (Dirks et al., 1977). Finding the WRS using only one presentation level is not an accurate way of predicting PB_{max} (Wiley et al., 1995), but this method is most common in clinical practice mostly because the test time is decreased (DeBow & Green, 2000; Martin, Armstrong, & Champlin, 1994).

Speech perception testing can be done in quiet and in noise. When using speech-in-noise tests, the audiologist can evaluate an individual's performance in a background of noise. Speech-in-noise testing is particularly useful with individuals who have peripheral hearing loss (Wilson & Strouse, 2002) or suspected (Central) Auditory Processing Disorder, or (C)APD (Bellis, 2003). It is well known that background noise adversely affects speech understanding ability in these populations (Mendel, 2007). A moderate to moderately-severe SNHL can produce a wide range of scores for speech-in-noise tests (Killion et al., 2004). One individual with a moderate to moderately-severe SNHL may suffer from only a minimal signal to noise ratio (SNR) loss, while another with a similar audiogram may suffer from a more detrimental SNR loss (Killion, 2002).

Incidence of Word Recognition Testing Among Audiologists

Approximately 70-90% of audiologists routinely administer word recognition tests (DeBow & Green, 2000; Martin, Armstrong, & Champlin, 1994; Martin, Champlin,

& Chambers, 1998; Martin & Morris, 1989). According to a survey sent out to 500 certified audiologists in the United States, Martin and colleagues (1998) reported that 91% of the 218 responding audiologists regularly administer word recognition tests. While Martin and colleagues have sent several surveys to audiologists in the United States, DeBow and Green (2000) surveyed Canadian audiologists and found that 72% were routinely finding the word recognition percentage. Many studies have investigated the variability found in word recognition testing; to date there is no universal method being used when administering these tests (DeBow & Green, 2000; Martin, Armstrong, & Champlin, 1994; Martin, Champlin, & Chambers, 1998; Wiley et al., 1995). The assessment factors involved in obtaining a WRS change from one audiologist to another and some methods used to obtain the WRS conflict with valid published data; therefore, reducing the test efficacy and decreasing the quality of service to the patient (Wiley et al., 1995). Speech audiometry is one area of common audiologic practice where shortcuts are taken to either decrease test time or to simplify testing. Audiologists need to be aware of the various assessment factors that can affect obtaining an individual's WRS, as well as the patient factors that may have an effect on the WRS.

Assessment Factors Affecting Word Recognition Score

Different types of stimuli are used to obtain a WRS such as nonsense syllables, monosyllabic words, and sentences (McArdle & Hnath-Chisolm, 2009). The assessment factors involved in obtaining a WRS that may affect the score can typically be controlled by the audiologist. Factors in speech recognition testing that often differ and that can affect the WRS include: Speech materials (word list), number of test items, lexical factors (i.e. incidence of word use), patient's native language, presentation mode (monitored live voice or recorded), presentation level (intensity level), scoring method (whole word versus phonemic), and use of a carrier phrase (Gelfand, 2001; Martin et al., 1998; McArdle & Hnath-Chisolm, 2009; Wiley et al., 1995). For a more detailed description of each assessment factor, the reader is referred to Paroly (2011).

Patient Factors Affecting Word Recognition Score

While many of the assessment factors can be controlled by the audiologist and a WRS can be obtained accurately and efficiently by using the published standards for testing, certain patient factors that result from SNHL cannot be so easily controlled and may negatively affect the diagnostic value in obtaining a WRS (Crandell, 1991; Gelfand, 2001; Humes, 1996). Individuals with hearing loss commonly complain that they can hear speech but that they cannot understand what is being said (Gelfand, 2001; Wilson & Strouse, 2002). This loss of clarity can occur from peripheral hearing loss due to cochlear damage or auditory nerve lesions (Moore, Glasberg, & Stone, 2004; Starr, Picton, Sininger, Hood, & Berlin, 1996). A review was put out by The Working Group of the Committee on Hearing and Bioacoustics and Biomechanics of the National Research Council (CHABA, 1988) that looked at three hypothesized reasons for speech understanding difficulty in adults aged 60 years and older: the peripheral, central-auditory, and cognitive hypotheses (CHABA, 1988; Crandell, Henoch, & Dunkerson, 1991; Humes, 1996). It is possible and very likely that all three mechanisms, peripheral, central-auditory, and cognitive, affect speech understanding in the elderly population (CHABA, 1998; Crandell, 1991; Weinstein, 2000).

In follow-up studies investigating the three hypotheses concerning speech understanding in the elderly, the peripheral hypothesis was most accurately associated with speech understanding performance in the elderly (Humes, 1996; Humes & Christopherson, 1991). Many patients with sloping high-frequency hearing loss may have cochlear dead regions, which can be defined as "a region in the cochlea where inner hair cells (IHCs) and/or neurons are functioning so poorly that a tone producing peak vibration in that region is detected by off place listening (i.e. the tone is detected at a place where the amount of basilar membrane vibration is lower, but the IHCs and neurons are functioning more effectively)" (Moore, 2004, p. 114). Individuals with high-frequency dead regions may not benefit from high-frequency amplification (above 3 kHz), especially when the degree of hearing loss exceeds 55 dB HL (Moore, 2001; Turner & Cummings, 1999). The peripheral portion of the auditory system, specifically the cochlea and auditory nerve, typically deteriorates with age (Humes, 1996; Humes & Christopherson, 1991). While Humes and Christopherson (1991) found that age (i.e. auditory processing and cognitive ability) does have an effect on speech identification performance, specifically for individuals 75 years and older; the primary factor underlying the speech understanding difficulties of the hearing-impaired elderly is their SNHL.

The degree of SNHL among elderly individuals, or the age-related changes in the auditory peripheral system, mostly influenced the differences in speech understanding performance (Humes, 1996). However, controversy exists in the literature in this area. Elderly individuals with peripheral hearing loss suffer injury to the entire auditory function, which includes the brainstem and the auditory cortical structures where cognition occurs (Rönnberg, 2003; Veras & Mattos, 2007). According to Veras and Mattos (2007), "Hearing as a whole involves not only 'hearing', but also the understanding of what is 'heard', which is compromised and requires special attention from the professionals involved in audiology and aging" (p. 123). Plomp (1978) described hearing loss for speech as the sum of attenuation and distortion and reported that the latter is primarily responsible for difficulties experienced in background noise. Paroly (2011) provides a thorough description of these patient factors that affect the WRS.

Effects of Masking on Word Recognition Score

Along with peripheral hearing loss, auditory processing disorder, cognitive function, and cochlear dead regions, masking is a factor that can affect an individual's WRS and can not necessarily be controlled. Masking is present when one sound (the masker) interferes with the ability to hear or covers up another sound (masked sound). When the masker and masked sound are both present in the same ear at the same time, this is called simultaneous masking. When the masked sound and the masker are not presented simultaneously (the two sounds arrive at the listener in succession), this is called temporal masking. Wegel and Lane (1924) used pure tones of different frequencies and intensities to examine masking patterns and found several facts about simultaneous masking. One finding was that masking spreads to frequencies higher than the masker, or that low-frequency signals mask high-frequency signals, especially at high intensity levels (Wegel & Lane, 1924). This phenomenon that occurs when a sound (masker) is loud enough to cover up frequencies above the masker, but not frequencies below the masker, is called the upward spread of masking (USOM) (Gagné, 1988; Wegel & Lane, 1924).

The USOM is best understood when one comprehends the anatomical and physiological functioning of the basilar membrane of the cochlea. Acoustic waveforms (sound) are converted into electromechanical stimuli and transmitted to the central nervous system (CNS) via the inner ear. The basilar membrane (BM) of the cochlea, which is housed in the inner ear, undergoes an oscillatory motion specific to the frequency of the incoming sound and it changes in stiffness and mass as sound arrives and travels down the BM (Gelfand, 2001; von Bekesy, 1960). One of the basic properties of the traveling wave is that it always travels from the base to the apex of the cochlea (Gelfand, 2001). Also, the traveling wave gradually increases in amplitude along the BM until it reaches the point at which it vibrates best (dependent on the frequency of the stimulus and on the mass/stiffness characteristics of the basilar membrane at that locus) and then the wave rapidly decays (Gelfand, 2001; von Bekesy, 1960).

As high-frequency sounds are introduced into the cochlea, the maximum amplitude of vibration occurs at the basal end of the cochlea; while lower frequency sounds entering the cochlea maximally vibrate the basilar membrane closer to the apical end of the cochlea. Once the maximum displacement of the basilar membrane has occurred, the wave abruptly declines in the more apical regions of the membrane (Dallos, 1992; Gelfand, 2001; von Bekesy, 1960). The basilar membrane can be thought of as a finely tuned band-pass filter in which the outer and inner hair cells (OHCs and IHCs) of the cochlea play essential roles in the sensorineural transduction process. Because the excitation pattern is larger for higher intensity signals and the traveling wave envelope is increasing through the basal end of the cochlea (high-frequency portion) and then decreasing through the apical end of the cochlea (low-frequency portion), low-frequency stimuli can mask high-frequency stimuli; hence, the USOM (Gagné, 1988; Gelfand, 2001; Wegel & Lane, 1924).

Upward spread of masking by an external noise source. Although there are many hypotheses for speech recognition deficits in hearing-impaired individuals, a well-known characteristic of listeners with SNHL is the inability to understand speech when the listening environment is not ideal (Crandell, 1991; Gelfand, 2001). Amplified lower frequency signals such as background noise may mask out essential high-frequency information, especially in listeners with high-frequency SNHL (Crandell, 1991; Hannley & Dorman, 1983). This masking of high-frequency information decreases one's ability to understand speech in a background of noise because consonants are generally higher in frequency and lower in amplitude than vowels and must be heard and distinguished in order to understand speech (Klein, Mills, & Adkins, 1990; Phillips, Richter, & McPherson).

Several investigators have examined the effects of masking on individuals with SNHL (Gagne, 1988; Martin & Pickett, 1970; Trees & Turner, 1986). Previous studies have shown that the degree and type of hearing loss can influence the amount of upward spread of masking. Martin and Pickett (1970) concluded that the degree of hearing loss must be taken into account when evaluating USOM in both normal and impaired ears.

When comparing data from individuals with SNHL and individuals with normal hearing, Gagne (1988) obtained thresholds in quiet from the hearing impaired group and also calculated an “expected” masked threshold; which was the greater of the mean normal masked threshold or the threshold obtained in quiet, from the hearing impaired individual. The amount of excess spread of masking (the decibel difference between the masked threshold and the “expected” masked threshold) for the listener with SNHL was greatest in the frequency region where the quiet thresholds were roughly equal to the “expected” masked thresholds, suggesting that listeners with SNHL display greater than normal amounts of upward spread of masking Gagne, 1988). Trees and Turner (1986) also found that masking differences existed between the SNHL population and the normal hearing population when the hearing-impaired quiet thresholds differed from the normal thresholds; or in the sloping portion of the hearing loss where thresholds were elevated.

Masking patterns, USOM, and speech recognition have been assessed in listeners with SNHL in the presence of low-frequency noise and under low-frequency gain reduction conditions (Bray & Thibodeau, 1992; Cook et al., 1997; Fabry, Leek, Walden, & Cord, 1993; Van Tasell & Crain, 1992). Overall, findings revealed that USOM was greatest in the presence of low-pass noise (600-900 Hz bandpass) and that somewhat less USOM was evident when a low-frequency gain reduction hearing aid was employed, especially at high noise levels. Additionally, an improvement in speech recognition was generally found with the low-frequency gain reduction (Cook et al., 1997; Fabry et al., 1993).

Research is ongoing in order to improve the speech perception abilities in noise for individuals with SNHL. Hearing aid algorithms have been employed to reduce low-frequency noise in order to improve the speech understanding abilities of individuals with SNHL (Chung, 2004; Cook et al., 1997; Fabry et al., 1993; Gatehouse, Naylor, & Elberling, 2006). High-pass filtering has also been employed in adaptive frequency response (AFR) hearing aids in order to reduce the upward spread of masking and therefore improve speech recognition scores (Fabry et al., 1993). These developments have successfully been able to improve the word recognition abilities of individuals with SNHL, particularly high-frequency SNHL.

Upward spread of masking by amplified low-frequency speech. The distortion of speech sounds that occurs from low-frequency noise can typically be controlled with the noise reduction technology available today; however USOM can occur due to amplified low-frequency speech. Gatehouse, Naylor, and Elberling (2006) assessed listening comfort, satisfaction, reported intelligibility, and speech test performance in 50 listeners with SNHL and five different hearing aid fittings. Two linear reference conditions and three two-channel compression fittings with different mixtures of fast and slow release times in the low- and high-frequency channels were assessed. Using the five hearing aid fittings and speech stimuli, susceptibility to spectral and temporal smearing and also to USOM was analyzed. As suspected, listeners with SNHL benefited from fittings with fast-acting wide dynamic range compression (WDRC) in the low-frequency channel and slow automatic volume control (AVC) processing in the high-frequency channel (Gatehouse, Naylor, & Elberling, 2006). By applying compression in the low frequencies, there is less chance for USOM.

Fabry et al. (1993) investigated the use of adaptive frequency response (AFR) hearing aids in eight subjects with precipitously sloping high-frequency SNHL to see if a reduction in the upward spread of masking was found and if speech recognition improved as a result of this reduction. Supporting the findings of Gagne (1988) and Trees and Turner (1986), individuals with precipitously sloping high-frequency SNHL demonstrate USOM; Fabry and colleagues (1993) sought to discover whether USOM was actually excessive in this population and if the filtering technique employed in AFR hearing aids would reduce the USOM and improve speech recognition. Results revealed USOM in excess for many hearing-impaired subjects. Another significant finding was that speech recognition improved in hearing-impaired individuals with the use of AFR hearing instruments using high-pass filtering techniques (Fabry et al., 1993). The improvement in speech recognition was likely due to the reduced upward spread of masking that occurred as a result of the high-pass filtering.

Goedegebure, Hulshof, Maas, Dreschler, & Verschuure (2001) utilized low-frequency reduction and high-frequency emphasis filtering techniques to decrease the USOM and reduce the speech dynamics at high frequencies when measuring speech intelligibility. Speech recognition scores were obtained from listeners with moderate to severe sloping SNHL using three types of phonemic compression in combination with the anti-USOM (AU) and the high-frequency emphasis control (HFEC) filtering. Both techniques used with compression control produced improved vowel intelligibility in quiet, and the HFEC significantly improved vowel intelligibility when testing was administered in a background of multi-talker babble noise (Goedegebure et al., 2001).

The findings of Goedegebure et al. (2001) can be applied directly to the current study. Listeners with sloping SNHL were examined to assess speech intelligibility. In many cases, these listeners have preserved low-frequency hearing sensitivity, and therefore depend heavily on low- and mid-frequency speech cues. In an environment with a high signal-to-noise ratio (SNR) these individuals will have difficulty picking out high-frequency cues, and may rely more on low- and mid-frequency speech information. Low-frequency reduction dominates those crucial speech cues in a background of noise, and therefore was not a favorable filtering technique to reduce USOM (Goedegebure et al., 2001; Goedegebure, Goedegebure-Hulshof, Verschuure, & Dreschler, 2002).

Statement of Purpose

Many studies have shown that using a single presentation level to obtain the WRS does not achieve the individual's maximum recognition ability (PB_{max}) (Guthrie & Mackersie, 2009; Kamm, Morgan, & Dirks, 1983; Wiley et al., 1995), especially in those with SNHL. However, the use of a single presentation level, typically a specific sensation level above the SRT, is widely used in clinical environments. If clinicians continue to use only one presentation level when obtaining a WRS, which is a method routinely practiced but not supported with evidence (Wiley et al., 1995) than an acoustically modified word list constructed to improve speech understanding for individuals with SNHL could provide more accuracy during such testing.

Although research exists in this area, minimal research has been conducted to look at reduced speech understanding caused by the USOM due to amplified low-frequency elements of speech. At this point, there are no methods used to control for this phenomenon. The purpose of this study is to examine the speech perception abilities of individuals with flat or sloping mild to moderately-severe SNHL both in an unmodified condition and in three conditions in which the speech stimuli have been acoustically modified (mid- to high-frequency regions of speech stimuli amplified). The assumption is that by proving this additional energy and reducing the upward spread of masking, participants will have improved speech perception abilities. The benefit shown when a high-frequency emphasis (HFEC) filter was used (Goedegebure et al., 2001) lends support to the current study, in which mid- and high-frequency regions of speech were modified in order to improve speech intelligibility by reducing the upward spread of masking. The data found in this study could contribute to a more accurate and precise test battery for audiologists to use when predicting patients' aided performance.

CHAPTER 3

METHODOLOGY

Methodology was taken from the pilot study by Paroly (2011). Word and sentence tests were acoustically modified by providing additional energy to the mid- and high-frequency regions of the speech stimuli (Paroly, 2011). Low frequency regions remained the same while mid- and high-frequency bands were increased in order to enhance speech clarity by reducing the amount of USOM. The speech recognition tests were then administered to participants in order to examine the scores of individuals with SNHL to see if their speech understanding improved with the modified word lists.

Participants

Participants included 28 volunteers with SNHL. They were recruited through the Center for Amplification, Rehabilitation, and Listening (CARL) database as well as through the Speech, Language and Hearing Center at Towson University. For the purpose of this study, inclusion criteria for participants were determined to be any individual with a flat or sloping SNHL ranging from mild to moderately-severe (pure-tone air conduction thresholds greater than or equal to 25 dB HL and less than or equal to 75 dB HL for the frequency range of 250-8000 Hz). Sensorineural hearing loss was diagnosed if the participant had no air-bone gaps (bone conduction thresholds within 10 dB HL of air conduction thresholds at each frequency) and normal tympanometry results. Exclusion from the study was warranted if a participant had threshold responses exceeding the limits of the audiometer at any test frequency or had an asymmetrical hearing loss (decibel difference of 25 dB or more per octave).

Approval from the Towson University Institutional Review Board (IRB) preceded any testing. Appendix A displays a copy of the IRB approval form, as well as a renewed approval form. All participants in this study signed an informed consent form, which is in compliance with guidelines established by the Towson University IRB, before participating in the study. Additionally, each participant was administered a brief six-item cognitive screener prior to testing in order to identify any participants with cognitive impairment (Callahan, Unverzagt, Hui, Perkins, & Hendrie, 2002). Participants were identified by number in all collected data, and identities were not exposed. Participants did not receive any monetary payment for participating in the study.

Development of Speech Stimuli

Speech stimuli from Paroly (2011) were used in this study. A brief overview is given of how these stimuli were developed; please see Paroly (2011) for a more thorough explanation. Initially, two 50-word NU-6 lists were combined to develop a 100-word list and two sequential 10-sentence Hearing-in-Noise Test (HINT) lists were combined to develop a 20-sentence list. Speech reception thresholds for sentences (RTS) values will be obtained using these HINT lists. The overall intensity of the NU-6 list, HINT sentences, and a Speech Intelligibility Rating (SIR) passage and their individual calibration tones were decreased by 10 dB SPL, 22 dB SPL, and 1dB SPL respectively, to help control for peak clipping when the lists would be acoustically modified.

In order to construct acoustically modified word lists for the experimental conditions, three filters were developed using audiometric data from past subjects who had participated in various CARL Lab studies at Towson University. A 1000 Hz cutoff frequency was used in all three filter conditions; the first filter (5 dB/octave), the second filter (2 dB/octave), and the third filter (8 dB/octave). Table 1 (from Paroly, 2011) lists the filter specifications.

Table 1

Filter Specifications

Filter	Cutoff Frequency (Hz)	Slope (dB/octave)
2 dB/octave	1000	2
5 dB/octave	1000	5
8 dB/octave	1000	8

Paroly (2011) applied the three filter settings to the original NU-6 and HINT speech tests using a graphic equalizer in the Adobe Audition version 1.5 software. The average root mean square (RMS) value of each speech test was then compared to the original speech test to ensure that no unwanted changes in intensity occurred within the software when the modified speech conditions were developed. The amplify task in the Adobe Audition software was used to adjust the RMS values of the modified NU-6 words and HINT sentences, to match the average RMS values found for the unmodified NU-6 and HINT lists. Of importance in the current study is that both the speech-shaped background noise, as well as the speech stimuli of the HINT test, were modified for all speech conditions. A compact disk (CD) was made from the Adobe Audition program of all of the modified speech conditions. This CD was used for testing participants throughout the study. Please see Table 2 for the speech lists, speech conditions, calibration tones, and track numbers for the SIR passages, NU-6 lists, and HINT lists (Paroly, 2011).

Table 2 *CD Track List*

SIR Passages			
Track	**Speech Condition**	**Ear**	**Combined Lists**
1	Calibration Tone	--	--
2	Unmodified	Right/Left	N/A
3	5 dB/octave Filter	Right/Left	N/A
4	2 dB/octave Filter	Right/Left	N/A
5	8 dB/octave Filter	Right/Left	N/A
NU-6 Lists			
Track	**Speech Condition**	**Ear**	**Combined Lists**
6	Calibration Tone	--	--
7	Unmodified	Right/Left	List 1A + 2A
8	5 dB/octave Filter	Right/Left	List 3A + 4A
9	2 dB/octave Filter	Right/Left	List 1B + 2B
10	8 dB/octave Filter	Right/Left	List 3B + 4B
HINT Sentences			
Track	**Speech Condition**	**Ear**	**Combined Lists**
11	Calibration Tone	--	--
12	Unmodified	Left	List 9 + 10
13	5 dB/octave Filter	Left	List 11 + 12
14	2 dB/octave Filter	Left	List 13 + 14
15	8 dB/octave Filter	Left	List 15 + 16
16	Unmodified	Right	List 17 + 18
17	5 dB/octave Filter	Right	List 19 + 20
18	2 dB/octave Filter	Right	List 21 + 22
19	8 dB/octave Filter	Right	List 23 + 24

Preliminary Test Procedures

All pure tone air and bone conduction thresholds and most comfortable listening levels (MCLs) were measured monaurally utilizing a Grason-Stadler Inc. (GSI) 61 clinical two-channel audiometer. Etymotic ER-3A insert headphones coupled to the ear canal with a foam plug were used to obtain threshold and MCL measurements from all participants. Air conduction thresholds at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz, and 8000 Hz, and bone conduction thresholds at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz were obtained using a pulsed pure tone stimulus and the ASHA modified Hughson-Westlake procedure (Katz, 2002) to verify that participants' current hearing loss met the inclusion criteria of the study. The GSI-61 was calibrated to ANSI S3.6-2003 standards within one year of testing. Prior to each session, audiometer calibration was performed to verify accurate attenuator linearity and output levels of the GSI-61 audiometer using a biologic listening check. Tympanometry was performed on the GSI Tympstar using a 226 Hz prone tone. For all testing, participants sat in a double walled sound-treated audiometric booth facing the examiner, who was in an adjacent control room.

Experimental Procedures

After obtaining pure tone air and bone conduction thresholds, MCLs for speech were obtained using the unmodified SIR passage (Cox & McDaniel, 1984) and a 7-point Likert scale. The Likert scale was created by Rensis Likert in the 1930s and is a commonly used tool that measures attitudes and opinions of respondents (Likert, 1932).

The most comfortable listening level was classified as a rating of '4' (i.e. “Comfortable”) on the scale. If the participant’s response was ‘4’ at multiple intensity levels, the highest intensity level labeled as a ‘4’ was chosen as MCL. The starting intensity was 40 dB HL and this was increased in four dB HL steps until the participant rated the intensity as ‘5’ (i.e. “Comfortable, but loud”). The intensity was then decreased in four dB steps until the participant responded with a ‘4’ and then the intensity was increased in two dB steps until a rating of ‘5’ was given again. This bracketing method was performed three times to ensure that an accurate MCL was chosen. The highest intensity level labeled a ‘4’ at least two out of three times was marked as the MCL, and this was accomplished for the unmodified condition.

The one-hundred word NU-6 list that was created for this study was employed to find WRS at the unmodified and filtered MCL. Participants repeated one hundred words back (open-set format) for each of the speech conditions; the unmodified condition, and the 2 dB/octave, 5 dB/octave, and 8 dB/octave filter conditions. A carrier phrase (i.e., “say the word…”) was always used in order to alert the participant to the stimuli and to produce the most accurate WRS (Gelfand, 1975). Instructions to the participant were as follows:

> In your right (or left) ear, you’re going to hear a short sentence. What I want you to do is please repeat the last word of the sentence. Some of the words may be difficult to make out, so if you’re unsure, please take a guess.

A whole word scoring technique was used to calculate a percent correct score (WRS) in the unmodified condition and in each of the filtered conditions.

Two consecutive 10-sentence lists were presented in the presence of 55 dB HL speech spectrum noise for each condition. HINT sentences were presented and an adaptive test procedure was employed to acquire RTS values (Nilsson, Soli, and Sullivan, 1994). The participant repeated back the first four HINT sentences in order to become familiar with the task. The starting intensity for sentence one was 44 dB HL. An intensity increase of four dB HL was implemented until the participant repeated the entire sentence back correctly. Depending on whether the participant was able to correctly or incorrectly repeat the sentence, a four dB HL increase or decrease was applied for the first four sentences. More precisely, the intensity was increased four dB HL if the participant could not correctly repeat the sentence and it was decreased by four dB HL if the participant was able to correctly repeat the sentence. This same adaptive procedure was employed for all HINT sentences; however, once sentence five was reached the intensity level was then increased or decreased in two dB HL steps through sentence 20. Instructions to the participant were as follows:

> In your right (or left) ear, you will be hearing sentences along with background noise. The volume of the noise will stay the same; however, the volume of the sentences will get slightly louder and slightly softer. What I want you to do is repeat back as much of the sentence as you can, even if you only heard part of the sentence. Please guess if you’re unsure, as some of these may be very difficult.

By averaging the presentation levels of the last 17 out of the 20 HINT sentences, the RTS were calculated for each of the four conditions.

Certain precautions were taken to ensure accuracy during testing for this study. Recorded word lists and sentence lists were utilized to safeguard from changes in pitch, voice quality, and rate of speech that can occur when monitored live voice presentation is used. As test time was approximately one hour, all participants were given a break between right ear testing and left ear testing to control for participant fatigue. Any order effects or learning effects were controlled for by randomization. Randomization was employed for the testing order between left and right earsand the presentation sequence of the four conditions. The testing sequence of the NU-6 and HINT tests was also randomized within each test for each of the four conditions. All randomizations were completed via an online randomization program (Randomizer.org). In the current study, participants acted as their own control. Word recognition scores and RTS values were obtained using the unmodified versions of the tests and then compared to the modified scores. This comparison evaluated the differences in scores to see if the acoustically modified speech recognition tests result in a change in speech perception abilities in individuals with mild to moderately-severe SNHL. See Table 3 for the audiometer set-up used for each test.

Table 3

Audiometer Set-up

SIR Passages

	Channel 1	**Channel 2**
Stimulus	N/A	External A
Transducer	N/A	Inserts
Routing	N/A	Right or Left
Steps	N/A	2 dB HL
Interrupt	OFF	ON

NU-6 Lists

	Channel 1	**Channel 2**
Stimulus	N/A	External A
Transducer	N/A	Inserts
Routing	N/A	Right or Left
Steps	N/A	2 dB HL
Intensity	N/A	MCL
Interrupt	OFF	ON

HINT Sentences

	Channel 1	**Channel 2**
Stimulus	External B	External A
Transducer	Inserts	Inserts
Routing	Right or Left	Right or Left
Steps	2 dB HL	5 dB HL
Intensity	Begin at: 44 dB HL	55 dB HL
Interrupt	ON	ON

Data Analysis

The data were analyzed using two repeated-measures analysis of variances (ANOVAs) with pairwise comparisons using the Least Significant Difference to control for an inflated alpha level. Repeated-measures ANOVAs, or within-subject ANOVAs or ANOVAs for correlated samples, are used when participants in the study are tested under the same conditions. If a significant difference was found between at least two of the conditions, then these differences were further via a pairwise comparison. Pairwise comparisons were made with the Least Significant Difference. Effect size was determined using the Partial Eta Squared (η^2_p) statistic.The first repeated-measures ANOVA was used to compare the effect of acoustically modified NU-6 word lists on speech understanding in the unmodified, 2 dB/octave filter, 5 dB/octave filter, and 8 dB/octave filter conditions. The dependent variable was the WRS (percent correct). The second repeated-measures ANOVA compared the effect of acoustically modified HINT sentences on speech understanding in the unmodified, 2 dB/octave filter, 5 dB/octave filter, and 8 dB/octave filter conditions. The dependent variable was RTS (in dB HL).

CHAPTER 4

RESULTS

A total of 28 participants with mild to moderately-severe symmetrical SNHL (ranging from 25 to 75 dB HL) were recruited for this study. Results were analyzed from 28 participants (56 ears), including nine male and nineteen female English speaking adults (age range = 24-94 years; *M* = 66.82, *SD* = 16.81). For a graphical representation of the individual audiometric air conduction thresholds obtained from the 28 participants with flat or sloping SNHL, refer to Figure 1 and Figure 2.

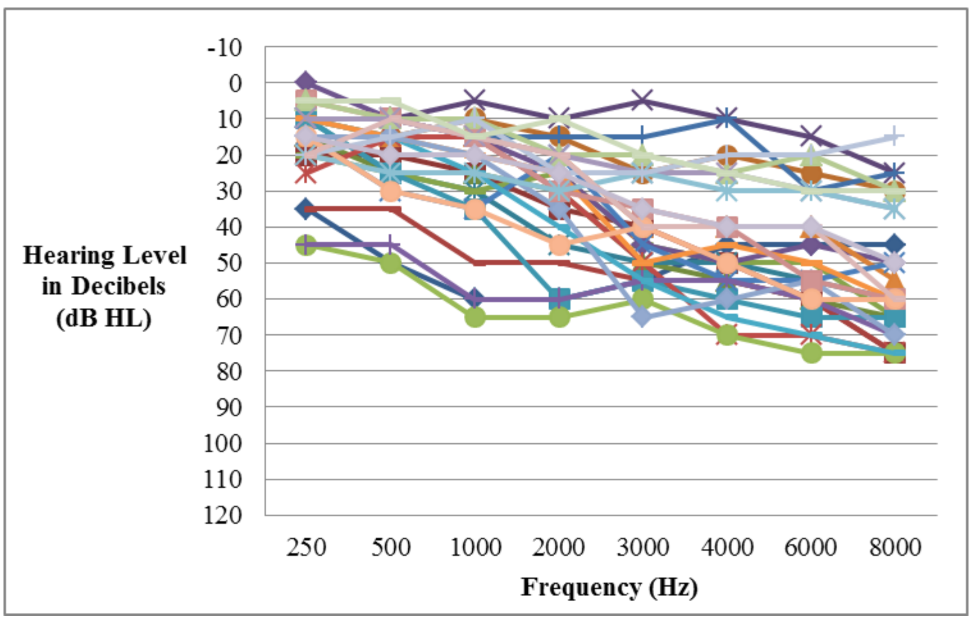

Figure 1. Individual audiometric air conduction thresholds in decibels hearing level (dB HL) at each test frequency (Hz) for the right ear.

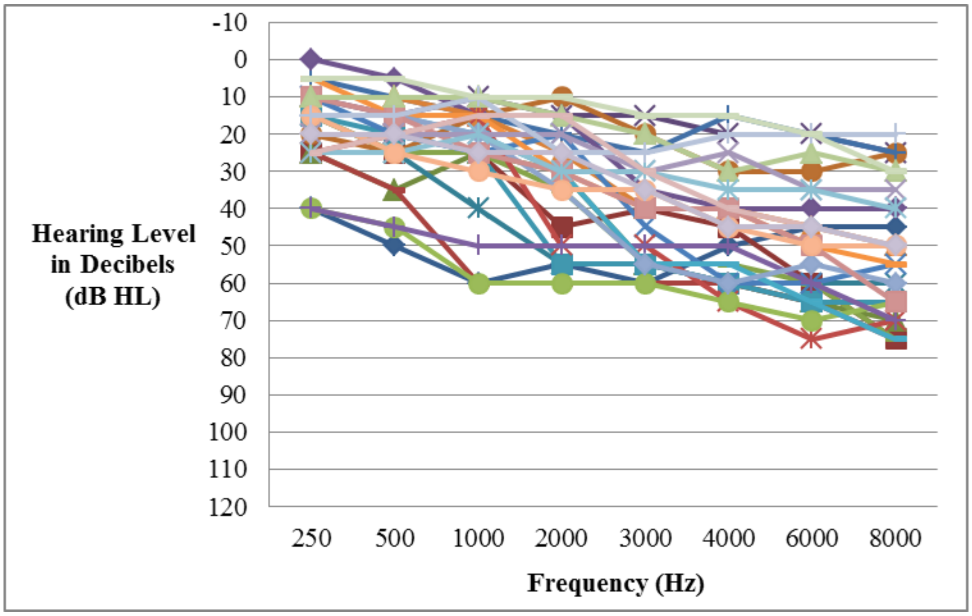

Figure 2. Individual audiometric air conduction thresholds in decibels hearing level (dB HL) at each test frequency (Hz) for the left ear.

Compairson Between Right and Left Ears

Paired-sample t-tests were conducted to determine whether results were different between the right and left ears in each condition. Results suggested no significant difference between the right and left ears in any of the conditions; therefore, the data for the right and left ears were combined for each condition. Refer to Figure 3 for the mean audiogram and standard deviations for all 28 participants after the right and left ear results were combined.

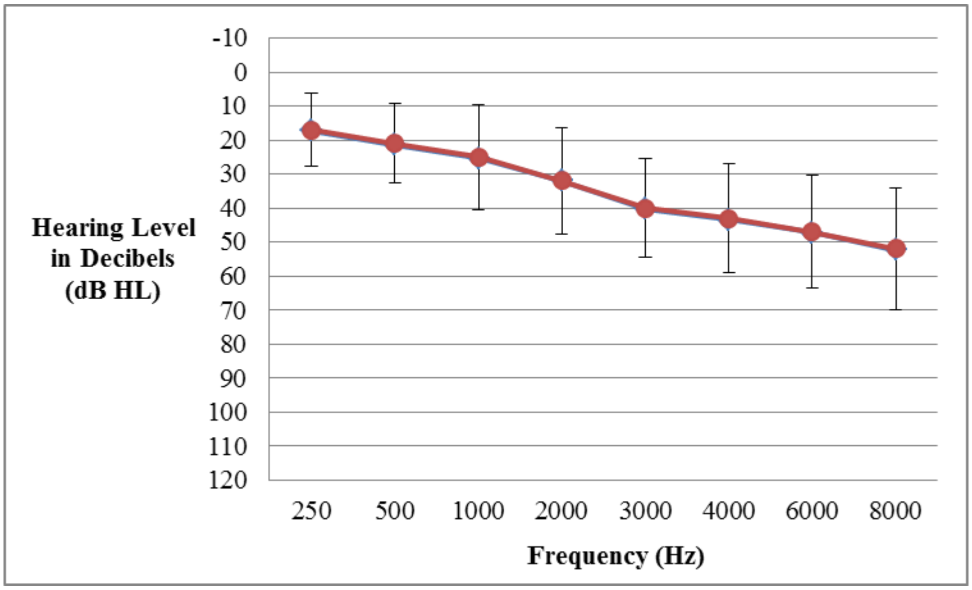

Figure 3. Mean audiometric air conduction thresholds in decibels hearing level (dB HL) at each test frequency (Hz) for right and left ears combined. Brackets represent one standard deviation above and below mean thresholds.

Most Comfortable Loudness Level (MCL)

Paroly (2011) utilized a repeated-measures analysis of variance (ANOVA) to compare the effect of acoustically modified SIR passages on MCL in the unmodified, 2 dB/octave filter, 5 dB/octave filter, and 8 dB/octave filter. No statistically-significant difference was found between any of the four conditions ($p > 0.05$). On average, there was less than a 2 dB difference between the MCL in the unmodified condition and the modified conditions (2, 5, and 8 dB/octave filtered conditions) in Paroly (2011). For these reasons, only the unmodified SIR passage was used to obtain MCL (range = 42-74, M = 59.39, SD = 7.47) in the present study.

Word Recognition Score (WRS)

A repeated-measures ANOVA with pairwise comparison using the Least Significant Difference was performed to compare the effect of acoustically modified NU-6 word lists on speech understanding in the unmodified, 2 dB/octave filter, 5 dB/octave filter, and 8 dB/octave filter conditions. Results indicated a significant main effect for filter condition: $F(3, 165) = 10.347$, $p < 0.001$, meaning that at least one of the four filter conditions was significantly different from the others.

A pairwise comparison using the Least Significant Difference indicated significantly higher (i.e. better) WRS in the 2 dB/octave filter condition ($M = 89$, $SD = 13.37$), the 5 dB/octave filter condition ($M = 88.34$, $SD = 13.18$), and the 8 dB/octave filter condition ($M = 89.35$, $SD = 12.60$) compared to the unfiltered condition. The unmodified condition yielded the lowest WRS ($M = 87.25$, $SD = 14.27$). A statistically significant increase was measured from the unmodified condition to the 5 dB/octave filtered condition ($p < 0.01$), and then from the 5 dB/octave filtered condition to the 2 dB/octave ($p < 0.05$) and 8 dB/octave ($p < 0.05$) filtered conditions. Participants' scores were highest in the 2 dB/octave and 8 dB/octave filtered conditions; however, no significant difference was observed between these two conditions ($p > 0.05$) (Table 4). See Figure 4 for mean WRS data. The effect size was examined using the Partial Eta Squared ($\eta^2_p = .158$). Cohen (1988) suggested that an r^2 (or η^2_p) of .1 represents a small effect size, .3 a medium effect size, and .5 represents a large effect size. According to Cohen (1988), an effect size of .158 is considered small.

Table 4

Pairwise Comparisons Between Each Speech Condition (unmodified [1], 2 dB/octave filter[2], 5 dB/octave filter [3], and 8 dB/octave filter[4]) for Word Recognition Score (WRS) Testing

(I) NU6	(J) NU6	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-1.089*	.382	.006	-1.854	-.325
	3	-1.750*	.364	.000	-2.480	-1.020
	4	-2.107*	.526	.000	-3.162	-1.052
2	1	1.089*	.382	.006	.325	1.854
	3	-.661*	.313	.040	-1.289	-.033
	4	-1.018*	.394	.013	-1.808	-.228
3	1	1.750*	.364	.000	1.020	2.480
	2	.661*	.313	.040	.033	1.289
	4	-.357	.431	.410	-1.220	.506
4	1	2.107*	.526	.000	1.052	3.162
	2	1.018*	.394	.013	.228	1.808
	3	.357	.431	.410	-.506	1.220

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

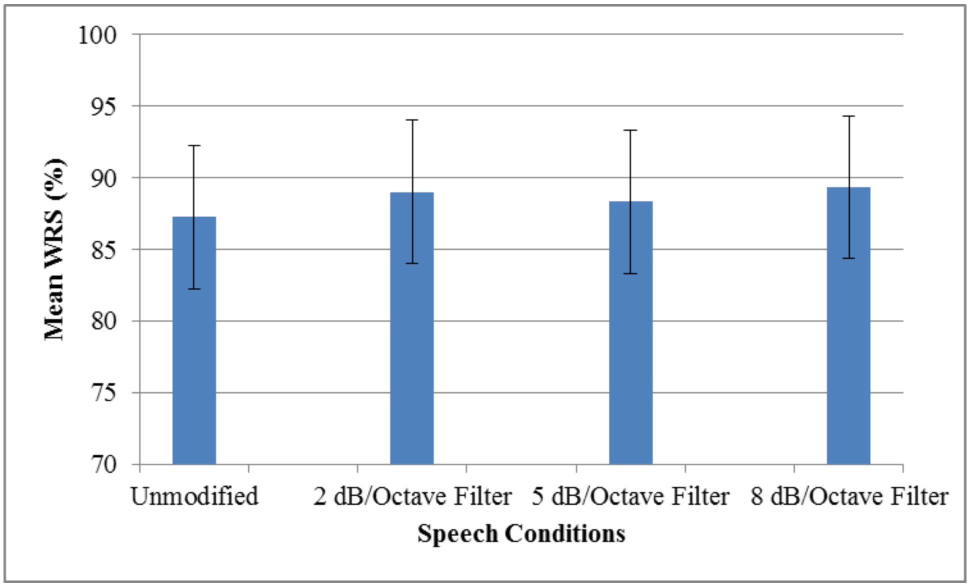

Figure 4. Mean Word Recognition Scores (WRS) for NU-6 lists in each speech condition (unmodified, 2 dB/octave filter, 5 dB/octave filter, and 8 dB/octave filter). Brackets represent one standard deviation above and below mean thresholds.

Reception Threshold for Speech (RTS)

Another repeated-measures ANOVA with pairwise comparison using the Least Significant Difference was performed to compare the effect of acoustically modified HINT sentences on speech understanding in the unmodified, 2 dB/octave filter, 5 dB/octave filter, and 8 dB/octave filter conditions. A significant main effect was found for filter condition: $F(3, 165) = 13.088$, $p < 0.001$, meaning that at least one of the four filter conditions was significantly different from the others. A pairwise comparison using the Least Significant Difference indicated a significant increase in RTS scores (i.e. worse performance) in the unmodified condition (M = 55.35, SD = 3.09) and a significant decrease in RTS scores (i.e. better performance) in the 8 dB/octave filter condition (M = 53.90, SD = 2.81). Pairwise comparison showed that significantly lower RTS scores were measured for the 2 dB/octave and 5 dB/octave filter conditions (M = 54.59, SD =

2.53; M = 54.44, SD = 2.62) when compared to the unmodified condition. No significant differences were observed when the 2 dB/octave and the 5 dB/octave conditions were compared. The RTS values were worst in the unmodified condition, better in the 2 dB/octave and 5 dB/octave conditions, and best in the 8 dB/octave filter condition. Pairwise comparisons between each speech condition for the HINT test can be seen in Table 5. See Figure 5 for mean RTS data. Effect size was examined, and a small effect size of .192 was obtained (Cohen, 1988).

Table 5

Pairwise Comparisons Between Each Speech Condition (unmodified [1], 2 dB/octave filter [2], 5 dB/octave filter [3], and 8 dB/octave filter[4]) for Reception Threshold for Speech (RTS) Testing

(I) HINT	(J) HINT	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.912*	.279	.002	.354	1.471
	3	.763*	.258	.004	.247	1.280
	4	1.454*	.294	.000	.865	2.042
2	1	-.912*	.279	.002	-1.471	-.354
	3	-.149	.158	.350	-.466	.168
	4	.541*	.198	.008	.144	.939
3	1	-.763*	.258	.004	-1.280	-.247
	2	.149	.158	.350	-.168	.466
	4	.690*	.188	.001	.313	1.067
4	1	-1.454*	.294	.000	-2.042	-.865
	2	-.541*	.198	.008	-.939	-.144
	3	-.690*	.188	.001	-1.067	-.313

Based on estimated marginal means
*. The mean difference is significant at the .05 level.
a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

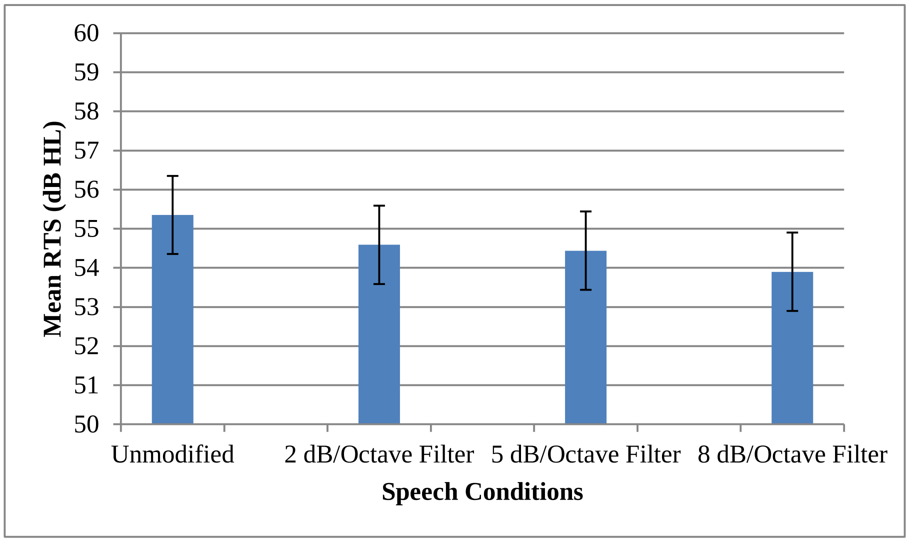

Figure 5. Mean Reception Thresholds for Speech (RTSs) for HINT sentences in each speech condition (unmodified, 2 dB/octave filter, 5 dB/octave filter, and 8 dB/octave filter). Brackets represent one standard deviation above and below mean thresholds.

Clinical Significance of NU-6 WRS Scores

Clinical significance for NU-6 testing was examined using the Thornton and Raffin (1978) binomial model. The binomial model table allows the clinician to quantitatively determine if two scores are to be considered significantly different (Thornton & Raffin, 1978). Although statistical significance was achieved for WRS in the acoustically modified conditions, no clinical significance was observed between the unmodified (M = 55.35, SD = 3.09) and the 2 dB/octave filter (M = 54.59, SD = 2.53) and 5 dB/octave filter (M = 54.44, SD = 2.62) conditions. Only participant 2 and participant 8 had a clinically-significant difference for at least one ear in the 8 dB/octave filter condition when compared to the unmodified condition.

Clinical Significance of HINT RTS Values

In order to evaluate clinical significance for RTS values, findings of Soli and Wong (2008) were used for data analysis. According to Soli and Wong (2008), a 1-dB increase in the RTS yields a 10% improvement in speech understanding in noise. The 2 dB/octave, 5 dB/octave, and 8 dB/octave filtered conditions were compared to the unmodified condition to see if participants had a clinically significant improvement in speech understanding from the unmodified HINT sentences to the acoustically modified HINT sentences. Clinical significance for changes in the RTS was observed in at least one of the filtered conditions in 54 out of 56 ears.

Figure 5 displays the number of ears with clinically significant RTS values (compared to the unmodified condition) in each filter condition. In the 2 dB/octave filter condition, 24 of 56 ears had clinically-significant changes to RTS. Similarly, 23 of 56 ears in the 5 dB/octave condition had clinically-significant changes, and 37 out of 56 ears had clinically significant RTS changes in the 8 dB/octave condition.

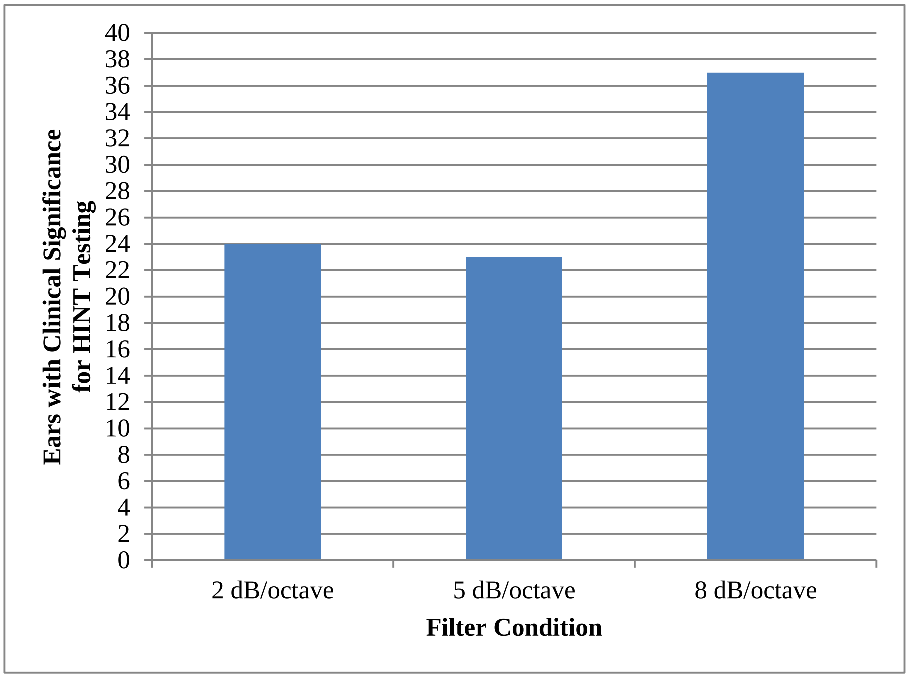

Figure 5. Number of ears in each filter condition (2 dB/octave, 5 dB/octave, and 8 dB/octave) with a clinically-significant difference in HINT RTS when compared to the unmodified condition.

A detailed chart (Table 6) displaying clinically-significance findings for the WRS and RTS values for each filter condition for the left and right ears of each participant can be found in Appendix G.

CHAPTER 5

DISCUSSION

The present study examined whether acoustically-modified speech stimuli would increase the speech understanding abilities of individuals with symmetrical mild to moderately-severe SNHL, in order to find if audiologists are actually measuring the maximum speech understanding of individuals with SNHL. Twenty-eight participants were recruited through the Center for Amplification, Rehabilitation, and Listening (CARL) database and the Speech, Language and Hearing Center at the Towson University Institute for Wellbeing (IWB). After signing an informed consent form approved by the Towson University Institutional Review Board (IRB), participants had to pass a brief cognitive screener and then tympanometry and pure tone air and bone conduction audiometry tests were administered. Next, an MCL was obtained using the SIR passage (unmodified) and speech perception abilities were measured using unmodified versions and acoustically-modified versions of NU-6 word lists and HINT sentences. In providing additional energy to the mid- and high-frequency regions of speech (2 dB/octave filter, 5 dB/octave filter, and 8 dB/octave filter), it was hypothesized that listeners with high frequency SNHL would perform better on speech understanding tasks due to the release from upward spread of masking (USOM). Results were analyzed from all 28 participants (56 ears), including nine male and nineteen female English speaking adults (age range = 24-94 years; *M* = 66.82, *SD* = 16.81). The results suggested that by adding energy to the mid- and high-frequency regions of NU-6 words and HINT sentences, participants showed a statistically-significant improvement in WRS and RTS scores and improved speech perception abilities. While clinical significance for most participants' improvement on the NU-6 was negligible, both statistical and clinical significance were found for a majority of the participants between the unmodified and the acoustically-modified HINT lists. These results are discussed in this section.

Word Recognition Score (WRS)

Results of the current study revealed a statistically-significant increase in WRS in the three filter conditions when compared to the unmodified condition. Participants performed best when the word lists were filtered at 2 dB/octave and 8 dB/octave. Although statistical significance was found for participants' performance in the 2 dB/octave and 8 dB/octave filter conditions, the mean scores between the unmodified and all three filtered conditions were very similar. A statistically-significant improvement was seen from the unmodified condition to the 5 dB/octave filter condition, and then from the 5 dB/octave filter condition to the 2 dB and 8 dB/octave filter conditions. Although these were small differences, participants did show a statistically-significant improvement in WRS in all three filtered speech conditions. It is possible that the performance across all conditions is indicative of ceiling effects. The reason why WRS was higher when NU-6 lists were filtered at 2 dB/octave and 8 dB/octave (versus the 5 dB/octave condition) is unclear at this time. Overall, these findings suggest that adding mid- to high-frequency energy to speech stimuli results in improved speech understanding for individuals with SNHL, likely due to a reduction in the USOM. Although statistical significance was found for the acoustically modified NU-6 lists on the WRS, these results were not clinically significant. Past studies have used automatic frequency response (AFR) hearing aids to reduce the USOM and improve speech understanding abilities in listeners with hearing loss (Fabry et al., 1993; Van Tasell & Crain, 1992). Similar to how the current study provided a boost in mid- and high-frequency energy to speech stimuli in order to reduce USOM, AFR hearing aids change frequency response to a more high-pass configuration when noise is present to reduce USOM and improve speech recognition (Fabry et al., 1993; Van Tasell & Crain, 1992). By reducing low-frequency gain, reducing the speech-to-noise ratio at higher frequencies, and employing a high-pass filter; the USOM effects are reduced with AFR hearing aids (Van Tasell & Crain, 1992). Fabry et al. (1993) also found that many subjects with high frequency SNHL demonstrated excess USOM, and consequently showed improvements in speech recognition as a result of high-pass filter in AFR hearing aids (reduced USOM).

Goedegebure and colleagues (2001) examined the use of phonemic compression (i.e. syllabic compression) in combination with anti-upward spread of masking techniques to assess the speech understanding of listeners with moderate to severe high frequency SNHL. The idea behind using phonemic compression in a high frequency channel was to improve consonant intelligibility, which is important for listeners with high frequency hearing loss as they typically have the most difficulty with consonant sounds. As described previously, consonant sounds (higher frequencies) contain less energy than vowel sounds (lower frequencies); Goedegebure et al. (2001) aimed to improve the performance of wide-band control (WBC) used in the single-channel phonemic compression. In other words, techniques were employed to reduce the negative effects of USOM. Of the two proposed solutions, additional low-frequency reduction at high levels to correct for USOM, and using high frequency emphasis of the compression control to decrease the speech dynamics in the high frequencies, the high frequency control compensated for USOM in quiet and in background noise (Goedegebure et al., 2001). Additionally, Goedegebure et al. (2001) suggest that low- and mid-frequency energy not be reduced for individuals with high frequency hearing loss because those are the speech cues that listeners depend on heavily in noisy conditions.

It is possible that clinical significance was only found for two participants between the unmodified NU-6 list and the three acoustically-modified NU-6 lists due to a ceiling effect. Participants scored similarly between the four conditions with the monosyllabic words presented in quiet. As it relates to predicting hearing aid benefit, presenting NU-6 words in a background of noise (in addition to or instead of presenting in quiet) would provide more beneficial information to the audiologist when it comes to how a patient may perform in everyday situations with hearing aids (Beattie, Barr, & Roup, 1997).

Reception Thresholds for Speech (RTS)

Along with the improvement in WRS in the acoustically-modified conditions, participants also performed better (i.e., had lower RTS scores) when the HINT sentences and HINT noise contained additional mid- and high-frequency energy. The lowest RTS scores were measured in the 8 dB/octave filter condition, and therefore the 8 dB/octave filter condition yielded statistically better RTS scores than any of the other conditions. An improvement was seen for the 2 dB/octave and 5 dB/octave filter conditions over the unmodified condition, but a significant difference was not measured between the 2 dB/octave and 5 dB/octave conditions. Although not statistically different, the mean RTS scores in the 5 dB/octave condition appeared to be better than the mean RTS scores in the 2 dB/octave condition; demonstrating a trend toward improvement across the four conditions as more high frequency emphasis was added. In other words, participants performed worst in the unmodified condition, and an improvement was observed from the unmodified condition to the more modified conditions. Statistical significance and clinical significance were found for RTS scores on acoustically-modified HINT sentences. These results suggest that listeners with mild to moderately-severe (high-frequency) SNHL perform better on speech understanding tasks in noise when a boost is applied to mid- and high-frequency energy of speech stimuli. Unlike the NU-6, the HINT cannot have ceiling or floor effects, other than the limits of the audiometer's attenuation circuitry, because it is an adaptive procedure in noise. It is likely that changes in speech perception scores were more easily observed with the HINT lists because they provide a more "real world" scenario. In other words, the HINT test may be more sensitive because it utilizes sentences in noise, and not just single words in quiet.

Although this same research question has not been asked outside of this study, the results may relate to another study that assessed the speech understanding abilities in noise of individuals with high frequency SNHL when additional high frequency emphasis was provided. Hornsby and Ricketts (2006) evaluated speech understanding in listeners with high frequency hearing loss and in listeners with normal hearing at multiple low- and high-pass filter cutoff frequencies. In examining the effect of configuration of hearing loss on the usefulness of amplified high frequency speech information in noise, they found that most subjects had improved speech understanding in noise when speech stimuli were high-pass filtered. Specifically, the subjects with sloping high frequency hearing loss (up to 60-80 dB HL) were able to use the amplified high frequency speech information (Hornsby & Ricketts, 2006). Similarly, the current study found that participants had higher RTS scores as more mid- to high-frequency energy was added to the HINT sentence lists. Many of these participants had sloping SNHL.

Study Limitations

Statistically-significant differences were found in WRS with NU-6 word lists and RTS scores obtained with HINT sentences in the unmodified condition versus scores obtained in all three acoustically-modified conditions. However, the findings from this study may not be applicable to the general population of individuals with hearing loss due to several limitations. Certain limitations discussed in Paroly (2011) were addressed in this study, such as increasing the number of participants, having a more diverse participant pool, and less strict criteria for degree of hearing loss. Nevertheless, limitations were still evident in the current study. The number of participants was increased from Paroly (2011); however, in order examine whether specific modified conditions would be better for specific slopes and degrees of hearing loss, more participants would be necessary to have a sufficient number of subjects in each group to ensure that the sample size would be representative of the larger population.

Also, less strict criteria for degree and configuration of hearing loss were employed than in Paroly (2011), resulting in hearing losses ranging from mild to moderately-severe (thresholds from 25 dB HL to 75 dB HL) with both flat and sloping configurations. Subjects were not grouped for data analysis based on the audiogram. For example, flat versus sloping configuration of hearing loss and the degree of the slope for sloping hearing losses was not accounted for in the analysis. A convenience sample of volunteers was used in the current study, and the inclusion criteria did not control for configuration or degree of slope. Further post-hoc analyses of the data would be necessary in order to determine whether degree and configuration of SNHL affects results; however, these analyses were outside of the scope of the present study.

Gordon-Salant (1984) compared the speech recognition performance of listeners with flat and (high frequency) sloping SNHL in three different hearing aid conditions in quiet and in noise. Each condition provided additional high frequency amplification, but the low frequency amplification was varied. Several results were obtained by Gordon-Salant (1984); however, of importance for future research is the finding that the USOM by high intensity speech was not observed in the flat audiogram group, but this phenomenon did occur in the high frequency hearing loss group. Hornsby and Ricketts (2006) examined the relative usefulness of speech cues in difference frequency regions for subjects with normal hearing, sloping hearing loss, and flat hearing loss (Hornsby &

Ricketts, 2003). Findings indicated that the relative utility of speech information in different frequency areas is affected by the configuration of hearing loss.

The present study also did not control for age and gender. Many researchers have reported that other elements, besides peripheral hearing loss, affect the speech understanding of individuals with hearing loss. Many factors associated with aging, such as auditory processing difficulty and declining memory and cognitive functioning, can influence the speech understanding abilities in the elderly population (CHABA, 1988; Pichora-Fuller, 2006; Veras & Mattos, 2007). As described by Veras and Mattos (2007), peripheral hearing loss in the elderly population generates problems in the entire auditory system (i.e. decline in central auditory processing) which often leads to a negative impact on communication and social relationships. Over half of the participants in the current study were over the age of 65. Future research may separate participants into groups by age. Nine male participants were included in the current study. According to Helfer (2001), high frequency hearing loss is more prevalent in men than in women and gender differences should be evaluated in research studies of this nature.

Two more limitations were noted. Neither Paroly (2011) nor the current study included normal-hearing control listeners. The inclusion of normal-hearing controls tested under identical conditions would contribute to the results obtained and the data analysis. Also, no subjective data were collected from the 28 participants in this study. Although participants performed significantly better in the acoustically-modified conditions for NU-6 lists and HINT sentences, all measures were objectively scored. It is possible that participants could have rated the 2 dB/octave, 5 dB/octave, or 8 dB/octave filter condition not as comfortable or clear as the unmodified condition. Follow-up studies should utilize this information to examine the speech understanding abilities of individuals with SNHL.

Future Research

Further research should be conducted in order to determine accurately the effects of acoustically modified speech tests on the speech perception abilities of individuals with SNHL. Many factors should be taken into account for future research. A larger sample size and more diverse participant pool (e.g. all age groups for the adult population represented) should be utilized in future studies in order to increase the validity and generalize findings to the whole population. Additionally, participants could be grouped based on the configuration of hearing loss (e.g. flat, sloping, small slope, medium slope, large slope), degree of hearing loss (e.g. mild, moderate, moderately-severe), and age (e.g. young, middle age, old, elderly) in order to assess differences in these areas. As mentioned in Paroly (2011), more filter conditions could be applied to the speech stimuli to account for areas of the audiogram where individuals' degree of hearing loss may have changed from a mild hearing loss to moderate or more severe. For example, three filter conditions could be created using a cutoff frequency of 500 Hz, and then the 500 Hz could be compared to the 1000 Hz crossover frequency. In addition to a cutoff frequency of 500 Hz, a cutoff frequency above 1000 Hz (2000 Hz) could also be employed. It should be noted that such modifications may be limited by the number of NU-6 lists.

Another consideration for future research is that obtaining subjective data from participants may be beneficial when applying the research to real-world situations.

Measuring data objectively, as was done in the current study, does not take into account each participant's subjective perception of the speech stimuli. An example of this would be if a participant performed significantly better in the 8 dB/octave filter condition for NU-6 words and HINT sentences, but a subjective questionnaire revealed that the participant felt the speech stimuli filtered at 8 dB/octave were not as clear, too tinny, or less comfortable when listening. Outcome data similar to those obtained in Cox, Johnson, and Alexander (2012) would be beneficial for future research. Analysis in Cox et al. (2012) was based on speech understanding results obtained in the laboratory, real-life ratings of amplified speech, and subjective measures of patient preferences.

Throughout the literature, there is question regarding the benefit that individuals receive from high frequency amplification when the degree of hearing loss is of a certain severity, or if an individual has cochlear dead regions, or if individuals have underlying factors aside from peripheral hearing loss that might be affecting speech perception (Amos & Humes, 2007; Cox et al., 2012; Humes & Christopherson, 1991; Preminger, Carpenter, & Ziegler, 2005; Veras & Mattos, 2007). Future research should take these factors into account as well. Several studies have shown that individuals with moderate-to-severe high frequency hearing loss do not receive benefit from high frequency amplification and in some cases they have performed more poorly, most likely due to neural dysfunction or inner hair cell damage (Hogan & Turner, 1998; Turner & Cummings, 1999). However, contradictory results have been found in the literature showing that listeners with high frequency hearing loss and even with cochlear dead regions receive some benefit from high frequency information (Cox et al., 2012; Vickers et al., 2001). Still, severe high frequency hearing loss, cochlear dead regions, and other factors such as age-related decline in auditory processing should be considered in future research.

Finally, only certain NU-6 and HINT lists were chosen for the modification of the speech stimuli in both the current study and Paroly (2011). In future studies, it is recommended that all lists be modified for all conditions, and then all of the lists should be randomized to control for potential order effects and learning effects.

Conclusion

The present study evaluated the effects of acoustically-modified speech stimuli on the speech perception abilities of individuals with flat or sloping mild to moderately-severe SNHL to determine whether maximum speech understanding of individuals with hearing loss is being obtained using the unmodified stimuli. Participants had improved WRS and RTS scores when the NU-6 word lists and HINT sentences contained additional mid- and high-frequency energy. Statistical significance was found for WRS as well as RTS scores; however, clinical significance was only found for RTS scores. This is likely due to a ceiling effect occurring during WRS testing as well as participants benefiting more from high-frequency information in a background of noise. Statistically-significant improvements in speech understanding, as measured by the WRS and RTS values, occurred when mid- to high-frequency energy was added to the NU-6 and HINT lists. These results suggest that the maximum speech understanding (PB_{max}) of patients may not be obtained with speech stimuli currently used for such testing. Audiologists should be aware of this phenomenon and attempt to account for the USOM when they are measuring patients' speech perception abilities. By obtaining the WRS with the use of modified speech stimuli such as those used in this study, it is possible that audiologists may be able to more accurately measure a patient's PB_{max}. Finding the maximum WRS will help the audiologist estimate communication impairment, rule out or provide further testing to aid in pathological ear disorder diagnosis, assess the need for amplification, estimate hearing aid benefit, and appropriately counsel the patient.

APPENDICES

Appendix A

TOWSON UNIVERSITY

APPROVAL NUMBER: 12-A044

APPROVED
FEB 29 2012
SM/WMP
TOWSON IRB

To: Cortney Butler
18 Tilton Court
Nottingham MD 21236

From: Institutional Review Board for the Proctection of Human Subjects, Steven Mogge, Member

Date: Wednesday, February 29, 2012

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

Office of University
Research Services

Towson University
8000 York Road
Towson, MD 21252-0001

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

Thank you for submitting an Application for Approval of Research Involving the Use of Human Participants to the Institutional Review Board for the Protection of Human Participants (IRB) at Towson University. The IRB hereby approves your proposal titled:

The effects of acoustically modified NU-6 and hearing in noise tests on speech perception abilities in individuals with sensorineural hearing loss

If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should your research extend beyond one year in duration, or should there be substantive changes in your research protocol, you will need to submit another application for approval at that time.
We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC: B. Kreisman
File

TOWSON
UNIVERSITY

Date: Wednesday, February 29, 2012

NOTICE OF APPROVAL

TO: Cortney Butler **DEPT:** ASLD

PROJECT TITLE: *The effects of acoustically modified NU-6 and hearing in noise tests on speech perception abilities in individuals with sensorineural hearing loss*

SPONSORING AGENCY:

APPROVAL NUMBER: 12-A044

The Institutional Review Board for the Protection of Human Participants has approved the project described above. Approval was based on the descriptive material and procedures you submitted for review. Should any changes be made in your procedures, or if you should encounter any new risks, reactions, injuries, or deaths of persons as participants, you must notify the Board.

A consent form: [✓] is [ ] is not required of each participant

Assent: [ ] is [ ] is not required of each participant

This protocol was first approved on: 29-Feb-2012
This research will be reviewed every year from the date of first approval.

Steve Mogge

Steven Mogge, Member
Towson University Institutional Review Board

TOWSON UNIVERSITY

RENEWED APPROVAL NUMBER: 12-A044R1

To: Cortney Butler
From: Institutional Review Board for the Protection of Human Subjects, Steven Mogge, Member
Date: Tuesday, April 02, 2013
RE: Application for Approval of Research Involving the Use of Human Participants

Office of University Research Services

Towson University
8000 York Road
Towson, MD 21252-0001

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

APPROVED APR 2 2013 TOWSON IRB

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

The effects of acoustically modified NU-6 and hearing in noise tests on speech perception abilities in individuals with sensorineural hearing loss

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

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

CC: B. Kreisman
File

Appendix B

TOWSON UNIVERSITY
INFORMED CONSENT FORM

Title of Investigation:
The effects of acoustically modified speech tests on the speech perception abilities of individuals with sensorineural hearing loss.

Principal Investigator:
Cortney Butler, B.S.
Doctor of Audiology (Au.D.) Candidate
Towson University
(443) 786-5332

Thesis Chair:
Brian Kreisman, Ph.D., CCC-A, FAAA
Calvin College
Speech Pathology and Audiology
3201 Burton SE
Grand Rapids, MI 49546
Office: (616) 526-7306
Email: bmk24@calvin.edu

Purpose of the Study:
The purpose of this study is to determine if modifying speech perception tests will result in increased speech understanding in people with hearing loss.

Procedures:
Your role in this study will consist of attending one two-hour experimental session. At this session, you will first have a hearing test completed. You will wear headphones to listen to tones and push a button when you hear them. If you qualify for the study, you must be willing to sign this informed consent document.

Following the hearing test, you will complete several tasks, including:

- Assess the volume of sentences to determine your most comfortable listening level
- Listen to words and sentences in your right ear with noise and in your left ear with noise, and repeat back what you heard

All testing will take place in a sound-treated booth in the Towson University Institute for Well-Being. All audiological and speech perception testing will be completed by a Doctor of Audiology (Au.D.) candidate.

Benefits:
It is hoped that the results of this study will provide information that may better help to assess an individual's potential communication abilities and determine eligibility for hearing aids.

Risks:
There are no known risks associated with participation in this study. Standard audiological testing will be employed. The sound intensity levels will be carefully monitored and will be no louder than your most comfortable listening level. Should the assessment become distressing to you, it will be terminated immediately.

Cost Compensation:
1. You will receive a free hearing test as a part of this study.
2. You will receive free parking for each visit.
3. There will be no monetary remuneration for participating in this study.

Rights as a Participant:
1. Your participation in this study will remain strictly confidential. Only the principal investigator and her supervisor will have access to the identities of the participants and information associated with their identities. Any data collected through the computer system will be labeled using a code number, which will be randomly

assigned to the subject. This computer will be password protected and all other information related to the study will be stored in a locked cabinet in the thesis chair's lab. Although the information may be published or presented, at no time will identifying information regarding participants be used.

2. Participation in this study is voluntary. At any time prior to or during the study, you are free to discontinue participation. A decision not to participate or to withdraw from the study will have no effect on your status or any current or future services you may be receiving at Towson University.
3. You are free to ask questions regarding the study and/or the test procedures. These questions will be answered by the investigator.
4. If you have any questions or problems that arise in connection with your participation in this study, please contact Cortney Butler, the principal investigator of this study at (443) 786-5332 or Dr. Debi Gartland, Chairperson of the Institutional Review Board for the Protection of Human Participants at Towson University at (410) 704-2236.

Informed Consent:

_____ I have read and understood the information on this form.

_____ I have had the information on this form explained to me.

____________________________________ ______________________________
Participant's Signature Date

____________________________________ ______________________________
Witness to Consent Procedures** Date

____________________________________ ______________________________
Principal Investigator Date

**If investigator is not the person who will witness participant's signature, then the person administering the informed consent should write his/her name and title on the "witness" line.

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

IRB Approval Number: 12-A044

Appendix C

7-point Likert Scale

7	Uncomfortably Loud
6	Too Loud
5	Comfortable, but loud
4	Comfortable
3	Comfortable, but soft
2	Too soft
1	Inaudible

Appendix D

NU-6 Word Lists

Note: These are the first 25 words of List 1A and 2A out of 16 variations of the original NU-6 Lists. Lists 1A, 2A, 3A, 4A, 1B, 2B, 3B, and 4B were used in the current study.

List 1A.

1. Laud
2. Boat
3. Pool
4. Nag
5. Limb
6. Shout
7. Sub
8. Vine
9. Dime
10. Goose
11. Whip
12. Tough
13. Puff
14. Keen
15. Death
16. Sell
17. Take
18. Fall
19. Raise
20. Third
21. Gap
22. Fat
23. Met
24. Jar
25. Door

List 2A

1. Pick
2. Room
3. Nice
4. Said
5. Fail
6. South
7. White
8. Keep
9. Dead
10. Loaf
11. Dab
12. Numb
13. Juice
14. Chief
15. Merge
16. Wag
17. Rain
18. Witch
19. Soap
20. Young
21. Ton
22. Keg
23. Calm
24. Tool
25. Pike

Appendix E

HINT Sentence Lists

Note: These are List 9 and List 10 out of 24 ten-sentence lists. Acceptable variations in responses are in parentheses.

List 9.

1. The cows (are/were) in (a/the) pasture.
2. (A/The) dishcloth (is/was) soaking wet.
3. They (have/had) some chocolate pudding.
4. She spoke to her eldest son.
5. (An/The) oven door (is/was) open.
6. She's paying for her bread.
7. My mother stirred her tea.
8. He broke his leg again.
9. (A/The) lady wore (a/the) coat.
10. The cups (are/were) on (a/the) table.

List 10.

1. (A/The) boy broke (a/the) wooden fence.
2. (An/The) angry man shouted.
3. Yesterday he lost his hat.
4. (A/The) nervous driver got lost.
5. (A/The) cook (is/was) baking (a/the) cake.
6. (A/The) chicken laid some eggs.
7. (A/The) fish swam in (a/the) pond.
8. They met some friends at dinner.
9. (A/The) man called the police.
10. (A/The) truck made it up (a/the) hill.

Appendix F

Test Sequences

NU-6 Lists and HINT Sentences

Participant	Ear	NU-6/HINT Order	WRS Condition	RTS Value Conditions
1	L,R	HINT, NU-6	1, UM, 3, 2	3, 2, UM, 1
2	L,R	HINT, NU-6	UM, 1, 2, 3	1, 2, UM, 3
3	L,R	NU-6, HINT	UM, 2, 1, 3	UM, 3, 1, 2
4	L,R	NU-6, HINT	UM, 2, 1, 3	3, 1, UM, 2
5	R, L	NU-6, HINT	1, UM, 2, 3	2, UM, 1, 3
6	L,R	NU-6, HINT	1, UM, 2, 3	UM, 2, 1, 3
7	L,R	NU-6, HINT	1, 2, UM, 3	UM, 3, 2, 1
8	R, L	NU-6, HINT	3, 2, UM, 1	1, 2, UM, 3
9	R, L	NU-6, HINT	2, 3, 1, UM	3, 1, 2, UM
10	R, L	HINT, NU-6	2, 1, 3, UM	1, 3, UM, 2
11	R, L	NU-6, HINT	1, UM, 3, 2	UM, 3, 1, 2
12	R, L	NU-6, HINT	3, 2, 1, UM	UM, 3, 1, 2
13	R, L	HINT, NU-6	UM, 1, 3, 2	2, 1, UM, 3
14	L,R	NU-6, HINT	2, 3, 1, UM	1, UM, 3, 2
15	L,R	NU-6, HINT	1, 2, 3, UM	3, UM, 2, 1
16	L,R	NU-6, HINT	2, 3, 1, UM	2, 3, 1, UM
17	L,R	HINT, NU-6	2, UM, 3, 1	3, 1, UM, 2
18	L,R	HINT, NU-6	UM, 2, 1, 3	2, 1, UM, 3
19	R, L	NU-6, HINT	3, UM, 2, 1	UM, 3, 2, 1
20	L,R	HINT, NU-6	1, 3, UM, 2	2, 3, UM, 1
21	L,R	NU-6, HINT	UM, 2, 1, 3	1, 3, UM, 2
22	R, L	HINT, NU-6	UM, 1, 3, 2	1, 2, 3, UM
23	L,R	NU-6, HINT	1, UM, 2, 3	1, UM, 2, 3
24	L,R	HINT, NU-6	3, 2, UM, 1	2, 1, UM, 3
25	L,R	HINT, NU-6	2, UM, 1, 3	3, UM, 1, 2
26	L,R	HINT, NU-6	2, 1, UM, 3	1, UM, 3, 2
27	R, L	NU-6, HINT	2, UM, 1, 3	UM, 3, 1, 2
28	L,R	HINT, NU-6	3, 1, 2, UM	1, UM, 2, 3

Key:

R: Right
L: Left

UM: Unmodified
1: Filter 1 (5 dB/octave)
2: Filter 2 (2 dB/octave)
3: Filter 3 (8 dB/octave)

Appendix G

Table 6

Clinical Significance findings for the NU-6 WRS scores and the HINT RTS scores for each filter condition for the left and right ears for each participant

Participant Filter:	2 dB/oct	5 dB/oct	8 dB/oct	Participant	2 dB/oct	5 dB/oct	8 dB/oct
NU-6 WRS Scores				**HINT RTS Values**			
1	-	-	-	**1**	-	-	-
2	-	-	L	**2**	R	R	R/L
3	-	-	-	**3**	R/L	R/L	R/L
4	-	-	-	**4**	R	-	-
5	-	-	-	**5**	L	L	R/L
6	-	-	-	**6**	-	L	R/L
7	-	-	-	**7**	-	-	L
8	-	-	R	**8**	-	L	L
9	-	-	-	**9**	L	R/L	L
10	-	-	-	**10**	R	-	R/L
11	-	-	-	**11**	R/L	R/L	R/L
12	-	-	-	**12**	-	-	-
13	-	-	-	**13**	R/L	R/L	R/L
14	-	-	-	**14**	R/L	R	L
15	-	-	-	**15**	L	R	-
16	-	-	-	**16**	R	R	R
17	-	-	-	**17**	R	R/L	L
18	-	-	-	**18**	R/L	L	R/L
19	-	-	-	**19**	R	-	R/L
20	-	-	-	**20**	-	-	L
21	-	-	-	**21**	R/L	-	R/L
22	-	-	-	**22**	-	-	L
23	-	-	-	**23**	R	-	R/L
24	-	-	-	**24**	-	L	R/L
25	-	-	-	**25**	R	R	R
26	-	-	-	**26**	R	R/L	R/L
27	-	-	-	**27**	-	-	L
28	-	-	-	**28**	-	R	R

Key:

R: Right ear L: Left ear

\- No significance found dB/oct: dB/octave

References

American Speech-Language-Hearing Association. (1988). Guidelines for determining threshold level for speech. *ASHA*, 1-12.

American Speech-Language-Hearing Association. (2006). Preferred practice patterns for the profession of audiology. *ASHA,* 1-79.

American Speech-Language-Hearing Association. (2011). Type, degree, and configuration of hearing loss. *ASHA Audiology Information Series.* Retrieved from http://www.asha.org/uploadedFiles/AIS-Hearing-Loss-Types-Degree-Configuration.pdf

Amos, N.E., & Humes, L.E. (2007). Contribution of high frequencies to speech recognition in quiet and noise in listeners with varying degrees of high-frequency sensorineural hearing loss. *Journal of Speech, Language, and Hearing Research, 50,* 819-834.

Beattie, R., Barr, T., & Roup, C. (1997). Normal and hearing-impaired word recognition scores for monosyllabic words in quiet and noise. *British Journal of Audiology*, *31*(3), 153-164.

Bellis, T. J. (2003). *Assessment and management of central auditory processing disorders in the educational setting from science to practice* (2nd ed.). Clifton Park, NY: Thomson.

Callahan, C.M., Unverzagt, F.W., Hui, S.L., Perkins, A.J., & Hendrie, H.C. (2002). Six-item screener to identify cognitive impairment among potential subjects for clinical research. *Medical Care, 40(*9), 771-781.

Chung, K. (2004). Challenges and recent developments in hearing aids: Microphone technologies and noise reduction algorithms Part I. *Trends in Amplification, 8(*3):83-124.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ England: Lawrence Erlbaum Associates, Inc.

Committee on Hearing and Bioacoustics and Biomechanics (CHABA) (1988). Speech understanding and aging. *Journal of the Acoustical Society of America, 83*, 859-895.

Cook, J.A., Bacon, S.P., & Sammeth, C.A. (1997). Effect of low-frequency gain reduction on speech recognition and its relation to upward spread of masking. *Journal of Speech, Language and Hearing Research*, *40(*2), 410-422.

Cox, R., Johnson, J., & Alexander, G. (2012). Implications of high-frequency cochlear dead regions for fitting hearing AIDS to adults with mild to moderately severe hearing loss. *Ear & Hearing*, *33*(5), 573-587.

Crandell, C. (1991). Individual differences in speech recognition ability: Implications for hearing aid selection. *Ear & Hearing, 12* (Suppl. 6), 100S-108S.

Crandell, C., Henoch, M., & Dunkerson, K. (1991). A review of speech perception and aging: Some implications for aural rehabilitation. *Journal of the Academy of Rehabilitative Audiology, 24,* 121-133.

Dallos, P. (1992). The active cochlea. *Journal of Neuroscience,12,* 4575–4585.

DeBow, A., & Green, W. (2000). A survey of Canadian audiological practices: Pure tone and speech audiometry. *Journal of Speech-Language Pathology and Audiology, 24(4)*, 153-161.

Dirks, D. D., Kamm, C.A., Bower, D., & Betsworth, A. (1977). Use of performance-intensity functions for diagnosis. *Journal of Speech and Hearing Research*, *42*, 408-415.

Dubno, J. R., Lee, F., Klein, A.J., Matthews, L.J., & Lam, C.F. (1995). Confidence limits for maximum word-recognition scores. *Journal of Speech and Hearing Research, 38*(2), 490-502.

Fabry, D., Leek, M., Walden, B., & Cord, M. (1993). Do adaptive frequency response (AFR) hearing aids reduce `upward spread' of masking? *Journal of Rehabilitation Research & Development*, *30(*3), 318-325.

Gagné, J. (1988). Excess masking among listeners with a sensorineural hearing loss. *Journal of the Acoustical Society of America*, *83*(6), 2311-2321.

Gatehouse, S., Naylor, G., & Elberling, C. (2006). Linear and nonlinear hearing aid fittings -- 2. Patterns of candidature. *International Journal of Audiology*, *45*(3), 153-171.

Gelfand, S.A. (2001). *Essentials of Audiology* (2nd ed.). New York: Thieme.

Goedegebure, A., Goedegebure-Hulshof, M., Verschuure, H., & Dreschler, W. (2002). The effects of phonemic compression and anti-upward-spread-of masking (anti-USOM) on the perception of articulatory features in hearing-impaired listeners. *International Journal of Audiology*, *41*(7), 414-428.

Goedegebure, A., Hulshof, M., Maas, R. J., Dreschler, W. A., & Verschuure, H. (2001).

Effects of single-channel phonemic compression schemes on the understanding of speech by hearing-impaired listeners. *Audiology*, *40*(1), 10-25.

Gordon-Salant, S. (1984). Effects of reducing low-frequency amplification on consonant perception in quiet and noise. *Journal of Speech & Hearing Research*, *27*(4), 483-493.

Guthrie, L. A., & Mackersie, C. L. (2009). A comparison of presentation levels to maximize word recognition scores. *Journal of the American Academy of Audiology*, *20(*6), 381-390.

Hannley, M., & Dorman, M. F. (1983). Susceptibility to intraspeech spread of masking in listeners with sensorineural hearing loss. *Journal of the Acoustical Society of America*, *74*(1), 40-51.

Hawley, M.E. (1995). Development of speech intelligibility measures and the ANSI standard. In C.W. Nixon (Ed.), *Symposium on Speech Communication Metrics and Human Performance* (pp. 3-13). Washington D.C.: Merry Spahr and Marty Luka of Systems Research Laboratories, Inc.

Helfer, K.S. (2001). Gender, age and hearing. *Seminars in Hearing*, *22(*3), 271-286.

Hogan, C.A., & Turner, C.W. (1998). High-frequency audibility: Benefit for hearing-impaired listeners. *Journal of the Acoustical Society of America*, *104*, 432-441.

Hornsby, B. Y., & Ricketts, T. A. (2006). The effects of hearing loss on the contribution of high- and low-frequency speech information to speech understanding. II. Sloping hearing loss. *Journal of the Acoustical Society of America*, *119*(3), 1752-1763.

Hornsby, B. Y., & Ricketts, T. A. (2003). The effects of hearing loss on the contribution of high- and low-frequency speech information to speech understanding. *Journal of the Acoustical Society of America*, *113*, 1706-1717.

Humes, L.E. (1996). Speech understanding in the elderly. *Journal of the American Academy of Audiology*, *7(*3), 161-168.

Humes, L., & Christopherson, L. (1991). Speech identification difficulties of hearing-impaired elderly persons: The contributions of auditory processing deficits. *Journal of Speech and Hearing Research*, *34*(3), 686-693.

Kamm, C. A., Morgan, D. E., & Dirks, D. D. (1983). Accuracyof adaptive procedure estimates of PB-Max level. *Journal of Speech and Hearing Disorders*, *48*(5), 202–209.

Killion, M. C. (2002). New thinking on hearing in noise: A generalized articulation index. *Seminars in Hearing*, *23*(1), 57-75.

Killion, M. C., Niquette, P. A., Gudmundsen, G. I., Revit, L. J., & Banerjee, S. (2004). Development of a quick speech-in-noise test for measuring signal-to-noise ratio in normal-hearing and hearing-impaired listeners. *Journal of the Acoustical Society of America*, *116*(4), 2395-2405.

Klein, A. J., Mills, J. H., & Adkins, W. Y. (1990). Upward spread of masking, hearing loss, and speech recognition in young and elderly listeners. *Journal of the Acoustical Society of America*, *87(*3), 1266-1271.

Kochkin, S. (2009). Market Trak VIII: 25-year trends in the hearing health market. *Hearing Review, 16(*11), 12-31.

Martin, F., Armstrong, T., & Champlin, C. (1994). A survey of audiological practices in the United States. *American Journal of Audiology, 3*, 20-26.

Martin, F., Champlin, C., & Chambers, J. (1998). Seventh survey of audiometric practices in the United States. *Journal of the American Academy of Audiology*, *9(*2), 95-104.

Martin, F., & Morris, L. (1989). Current audiological practices in the United States. *Hearing Journal, 42*, 25-42.

Martin, E.S., & Pickett, J.M. (1970). Sensorineural hearing loss and upward spread of masking. *Journal of Speech and Hearing Research, 13,* 426-437.

McArdle, R., & Hnath-Chisolm, T. (2009). Speech audiometry. In J. Katz, L. Medwetsky, R. Burkard, & L. Hood (eds.), *Handbook of Clinical Audiology* (6th ed.). Baltimore: Lippincott Williams & Wilkins.

Mendel, L. L. (2007). Objective and subjective hearing aid assessment outcomes. *American Journal of Audiology, 16*, 118-129.

Moore, B.C.J. (1998). *Cochlear Hearing Loss.* London: Whurr.

Moore, B. (2004). Dead regions in the cochlea: conceptual foundations, diagnosis, and clinical applications. *Ear & Hearing*, *25*(2), 98-116.

Moore, B. C. J., & Alcántara, J. I. (2001). The use of psychophysical tuning curves to explore dead regions in the cochlea. *Ear & Hearing, 22*, 268–278.

Moore, B.C.J., Glasberg, B.R., & Stone, M.A. (2004). Dead regions in the cochlea. *Ear and Hearing*, *25,* 478-487.

Nilsson, M., Soli, S., & Sullivan, J. (1994). Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. *The Journal of the Acoustical Society of America*, *95*(2), 1085-1099.

Paroly, L. (2011). *The effects of acoustically modified NU-6 and Hearing in Noise Tests on speech perception abilities in individuals with mid to high frequency sensorineural hearing loss.* (Unpublished doctoral thesis). Towson University, Maryland.

Phillips, S. L., Richter, S. J., & McPherson, D. (2009). Voiced initial consonant perception deficits in older listeners with hearing loss and good and poor word recognition. *Journal of Speech, Language and Hearing Research*, *52(*1), 118-129.

Pichora-Fuller, M.K. (2006). Effects of age on auditory and cognitive processing: Implications for hearing aid fitting and audiologic rehabilitation. *Trends in Amplification, 10(*1), 29-59.

Plomp, R. (1978). Auditory handicap of hearing impairment and the limited benefit of hearing aids. *Journal of the Acoustical Society of America*, *63*, 533-549.

Preminger, J. E., Carpenter, R., & Ziegler, C. H. (2005). A clinical perspective on cochlear dead regions: Intelligibility of speech and subjective hearing aid benefit. *Journal of the American Academy of Audiology*, *16*, 600-613.

Preminger, J., & Wiley, T.L. (1985). Frequency selectivity and consonant intelligibility in sensorineural hearing loss. *Journal of Speech and Hearing Research, 28*, 197-206.

Rönnberg, J. (2003). Cognition in the hearing impaired and deaf as a bridge between signal and dialogue: A framework and a model. *International Journal of Audiology,42*, S68-S76.

Schoepflin, J.R. (2012, July 30). Back to Basics: Speech Audiometry. Retrieved from http://www.audiologyonline.com/articles/back-to-basics-speech-audiometry-6828

Silverman, S. R., & Hirsh, I. J. (1955). Problems related to the use of speech in clinical audiometry. *Annals of Otology, Rhinology and Laryngology, 64*, 1234-1244.

Starr, A., Picton, T.W., Sininger, Y., Hood, L.J., & Berlin, C.I. (1996). Auditory neuropathy. *Brain, 119*, 741-753.

Studebaker, G.A., Sherbecoe, R.L., McDaniel, D.M., & Gwaltney, C.A. (1999). Monosyllabic word recognition at higher-than normal speech and noise levels. *Journal of the Acoustical Society of America*, *105(*4), 2431-2444.

Thornton, A. R., & Raffin, M. J. (1978). Speech-discrimination scores modeled as a binomial variable. *Journal of Speech & Hearing Research*, *21*(3), 507-518.

Trees, D.E., & Turner, C.W. (1986). Spread of masking in normal subjects and in subjects with high-frequency hearing loss. *Audiology, 25*, 70-83.

Turner, C., & Cummings, K. (1999). Speech audibility for listeners with high-frequency hearing loss. *American Journal of Audiology*, *8*(1), 47-56.

Turner, C., & Henry, B. (2002). Benefits of amplification for speech recognition in background noise. *The Journal of the Acoustical Society of America*, *112*(4), 1675-1680.

Van Tasell, D. & Crain, T. (1992). Noise reduction hearing aids: Release from masking and release from distortion. *Ear & Hearing*, *13*(2), 114-121.

Veras, R.P., & Mattos, L.C. (2007). Audiology and aging: Literature review and current horizons. *Brazilian Journal of Otorhinolaryngology*, *73***,** 122-128.

Vickers, D., Moore, B., & Baer, T. (2001). Effects of low-pass filtering on the intelligibility of speech in quiet for people with and without dead regions at high frequencies. *The Journal of the Acoustical Society of America*, *110*(2), 1164-1175.

von Békésy, G. (1960). *Experiments in hearing*. New York: McGraw-Hill.

Wegel, R.L., & Lane, C.E. (1924). The auditory masking of one pure tone by another and its probable relation to the dynamics of the inner ear. *Physiology Review, 23*, 266-285.

Weinstein, B.E. (2000). *Geriatric Audiology*. New York: Thieme.

Wiley, T.L., Stoppenbach, D.T., Feldhake, L.I., Moss, K.A., & Thordardottir, E.T. (1995). Audiologic practices: What is popular versus what is supported by evidence. *American Journal of Audiology, 4*, 26-34.

Wilson, R.H., & Margolis, R.H. (1983). Measurements of auditory thresholds for speech stimuli. In D.F. Konkle, & W.F. Rintelmann (Eds.), *Principles of Speech Audiometry* (Chapter 5, pp. 79-126). Baltimore: University Park Press.

Wilson, R., & Strouse, A. (2002). Northwestern university auditory test no. 6 in multi-Talker babble: A preliminary report. *Journal of Rehabilitation Research and Development*, *39*(1), 105-113.

CURRICULUM VITA

NAME: Cortney Butler

PERMANENT ADDRESS: 232 Claiborne Fields Dr.
Centreville, MD, 21617

PROGRAM OF STUDY: Audiology

DEGREE AND DATE TO BE CONFERRED: Doctor of Audiology, May 2014

Secondary education: Wesleyan Christian School, Denton, Maryland
Graduation date: June 2003

Collegiate Institution	Dates	Degree	Dateof Degree
Towson University	2007-2010	Bachelor of Science	May 2010
Towson University	2010-current	Doctor of Audiology	May 2014