Abstract

IMPACT OF AUDITORY TRAINING ON SPEECH PERCEPTION AND COGNITIVE ABILITIES IN OLDER ADULTS WITH HEARING LOSS

By

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The current study explored the impact of short term auditory training (LACE-Degraded) and auditory-cognitive training (LACE 4.0) on speech perceptual and cognitive measures in older adults with mild-moderate sensorineural hearing loss (SNHL). Thirty five participants, ages 60 to 80 years, with symmetrical mild-moderate SNHL completed a preliminary test battery of speech perceptual, cognitive, and self-report measures. The 35 study participants were randomly placed into one of three training groups (LACE 4.0, LACE-Degraded, or Short-Story Listening Training). Participants completed one week of training followed by post-testing. Multivariate Analysis of Variance was used to determine if significant improvements in speech perceptual, cognitive processing, and/or self-reported communication abilities occurred following the different training conditions. In addition, Pearson Product Moment correlation analyses were used to determine associations between experimental measures.

No significant differences were found for initial measures of speech perceptual, cognitive processing, or self-report communication abilities; age or hearing loss between the three groups. The main finding was improvement for the LACE 4.0 group with increased performance on some speech perceptual and self-report measures. No strong correlations were found between

changes in speech perception and initial measures of cognition or self-report. However, small to moderate significant correlations were found between selected speech perceptual measures, between cognitive processing measures, and between self-report measures. In the current study, tests sharing more common features tended to show significant correlations. Of interest, was a strong significant positive correlation that occurred between the Words in Noise test (speech perceptual measure) and the Time Compressed Speech test (processing speed measure). These two measures shared three out of five common task features and used words from the NU 6 word list. Unlike others studies, the current study focused on auditory and auditory-cognitive training in non-hearing aid users. These types of trainings may be a valid option for non-hearing aid users. Further confirmation of short-term training benefit is important because there is low compliance for completing the traditional longer training programs.

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CHAPTER I

Review of the Literature

Introduction

Bilateral progressive sensorineural hearing loss is the most common hearing loss in individuals 65 years and older (Seidman, Ahmad, & Bai, 2002; Shields, 2004). This type of hearing loss is known as *presbycusis* or *age-related hearing loss* (AHL). Presbycusis generally refers to age-related degenerative changes in the inner ear that result in hearing loss (Jennings & Jones, 2001). Schuknecht (1955) defined four main forms of presbycusis relative to age-related anatomical and physiological changes. These include sensory, neural, metabolic (also known as strial metabolic), and cochlear conductive (Heine & Browning, 2002; Mazelova, Popelar, & Syka, 2003; Shields, 2004; Roeser, Valente, & Hosford-Dunn, 2000). Hearing loss in older adults can have detrimental impact on the ability to effectively communicate. In general, as one ages, there are a number of structural and functional changes that occur within the biological systems of the body. That is, structurally, the loss of auditory hair cells and auditory neurons in the peripheral system can lead to functional changes related to the neuronal firing within the auditory system. These structural changes may further impact the functionality of the temporal properties (i.e., timing, intensity and phase) relative to the transmission of the signal throughout the central auditory system**.** Changes within the peripheral and central auditory system and cognitive areas (such as attention, working memory, and processing speed) contribute to speech processing deficits in older adults. This in turn may directly or indirectly impact social, vocational, emotional and intellectual abilities in the older adult (Kricos, 2006).

The purpose of this study is to explore speech perceptual and cognitive abilities in older adults with mild to moderate sensorineural hearing loss. This is a treatment study that will explore whether auditory training facilitates changes in the speech perceptual and cognitive abilities in older adults on pre and post training measurements. This literature review includes six main sections. In the first section, the nature of hearing loss will be discussed. The second section is a presentation of literature related to central auditory processing abilities in older adults and includes; flow of auditory information, the central auditory processing test battery, and effects of hearing loss and aging on central auditory processing. In the third section of the literature review, a discussion related to speech perceptual abilities of older adults with a primary focus on temporal processing will be presented. The fourth section addresses cognitive abilities in older adults and includes discussion related to; definition of cognition, memory, hearing loss and memory, attention, attention and audition, and processing speed. In the fifth section of the review, auditory training abilities in older adults will be addressed. The literature review will conclude with a summary and rationale, plan of the study, and experimental questions for the current investigation.

Nature of Hearing Loss

To understand the nature of hearing loss in older adults, it is necessary to discuss the normal auditory system. Anatomically, the ear is divided into three distinct parts: outer, middle, and inner. The outer ear (i.e., auricle and ear canal) collects sounds from the environment and transmits these sounds down the ear canal to the tympanic membrane. When the sound travels down the ear canal, it is resonated, resulting in an increase in sound pressure due to change in shape from the auricle through the tube-like shape of the ear canal. At the end of the ear canal, the sound is transferred from the outer ear into the air-filled middle ear through vibration of the tympanic membrane. Vibration is then transferred to the ossicles, consisting of the malleus, incus, and stapes. When the stapes vibrates, it moves against the oval window and sets fluid in the inner ear into motion, resulting in fluid pressure waves. These waves cause hair cells of the inner ear to shear against the overlying tectorial membrane. This action results in an electrochemical response from the hair cells that produces an electrical nerve impulse in the auditory portion of the vestibulo-cochlear nerve. The neural transmission moves from the peripheral auditory nervous system or auditory nerve to the central auditory system which includes the auditory brainstem and auditory cortex.

Hearing loss is defined as a "reduction in hearing sensitivity" (Stach, 2003, p.126), often related to congenital or acquired factors. Congenital hearing losses are attributed to conditions that affect the fetus during development or at the time of birth. Etiologies of congenital hearing loss include: genetic abnormalities, structural abnormalities of the ears or face, congenital infections, hypoxia and hyperbillirubinemia. Genetically, there are over 51 "auditory genes" known to cause hearing loss that are either syndromic or nonsyndromic in nature (Resendes, Williamson, & Morton, 2001, p. 923). Acquired hearing losses may be associated with meningitis, ototoxic medications, autoimmune infections, head trauma, aging, and noise exposure (Roizen, 2003). Older adults may have hearing loss attributed to both congenital and acquired factors.

In order to identify hearing loss, hearing sensitivity is evaluated across a range of frequencies with presentation of tones under earphones (at octave intervals typically from 250-8000 Hz) as well as presentation of tones via a bone conduction vibrator (typically at octave intervals from 250-4000 Hz). Once hearing sensitivity loss has been identified, type of loss can be categorized based on involved parts of the ear. Conductive hearing loss affects transfer of sound through the outer and/or middle portions of the ear. Sensorineural hearing loss affects function of hair cells and/or neural pathways of the inner ear. Mixed hearing loss involves both middle and inner portions of the ear. Two other descriptive categories used in evaluation of hearing loss include severity and configuration of the hearing loss. The degree or severity of hearing loss is determined by examining pure-tone air conduction thresholds or hearing sensitivity measures under earphones. Severity of hearing loss according to pure-tone air conduction thresholds can be categorized (Goodman, 1965) as follows: normal hearing (0-25 dB HL), mild loss (26-55 dB HL), moderate loss (56-70 dB HL), severe loss (71-90 dB HL) and profound loss (91-120 dB HL) (Marcincuk & Roland, 2002; Roeser, Valente, & Hosford-Dunn, 2000). The degree of hearing loss often varies across the frequency range so that the overall configuration of hearing thresholds is typically not flat in shape. Although there are various configurations of hearing loss, the most common ones associated with age-related hearing loss are flat, gradually sloping, and high frequency in nature (Jennings & Jones, 2001; Roeser, Valente, & Hosford-Dunn, 2000). In addition to these categorizations, hearing loss may be unilateral in which only one ear is affected or bilateral which affects both ears (Isaacson & Vora, 2003).

Research conducted with humans and animals has offered a greater understanding of the four forms of presbycusis. Sensory presbycusis affects the basal portion of the Organ of Corti, resulting in hair cell loss (particularly outer hair cell loss) and a high frequency steeply-sloping audiogram (DeStefano, Gates, Heard-Costa, Myers, & Baldwin, 2003). Neural presbycusis results in a loss of auditory neurons within the vestibulo-cochlear nerve. Audiometrically, neural presbycusis produces disproportionately poor speech recognition scores and a flat or sloping audiogram. Metabolic or strial presbycusis affects the “biomechanical environment of the cochlea” (Marcincuk & Roland, 2002, p. 55), resulting from degeneration of the stria vascularis, the vascular strip that normally supplies nutrients and oxygen to the portion of the cochlea that houses the hair cells. The audiometric configuration associated with metabolic presbycusis is a flat audiogram. Cochlear conductive or mechanical presbycusis (Jennings & Jones, 2001; Marcincuk & Roland, 2002) is purported to be due to changes in the thickness of the basilar membrane (basal portion) which produces a gradually sloping high frequency hearing loss (Gates & Mills, 2005; Jennings & Jones, 2001; Marcincuk & Roland, 2002; Shields, 2004; Roeser, et al., 2000). Animal studies conducted with mice, rats, gerbils, and chinchillas have provided evidence and support for the histological findings described (Gates & Mills, 2005, Gratton & Vazquez, 2003, Jennings & Jones, 2001). Furthermore, animal, human, and laboratory genetic studies provide evidence that the possible cause of the degenerative processes are within the cochlear structure (i.e., the stria vascularis and both the apical and basal regions of the cochlea) (Gates & Mills, 2005) as well as the molecular breakdown and genetic loci of the anomaly (DeStafano, et al., 2003; Jennings & Jones, 2001; Resendes et al., 2001; Seidman et al., 2002; Van Laer, Vrijens, Thys, Van Tendeloo, Smith, Van Bockstaele, Timmermans, & Van Camp, 2004). While presbycusis is primarily associated with the natural aging process, other contributing factors such as environmental exposure (e.g., noise, smoking, medications), genetic deficits, deoxyribonucleic acid (DNA) damage, and changes in the homeostasis of cellular environments also have been reported as potential causes (Gates & Mills, 2005; Seidman et al., 2002). Of these factors, genetic deficits in the function of the mitochondria (source of cellular energy) as well as other overlapping genetic loci that are known to cause syndromic and non-syndromic deafness in humans have been reported including Usher's syndrome types 1A, 1B and 1C, DFNB2, DFNB20 and DFNA15 (DeStefano et al., 2003; Jennings & Jones, 2001). Furthermore, the age-related hearing loss (ahl) gene in mice on chromosome 10 has been identified as the cause of presbycusis in the C57 mouse model (Seidmand et al., 2002).

Linkage analyses conducted by DeStefano et al. (2003) and Gates, Couropmitree, and Myers (1999) provide information from a large human cohort population regarding age-related hearing loss and the hereditability of presbycusis. Linkage analysis is genetic testing performed on chromosomal DNA to study the way genes are inherited from one generation to the next. Formally defined, linkage analyses are "studies aimed at establishing linkage between genes" (http://www.medterms.com/script/main/art.asp?articlekey=4166). The general consensus reported was that 35% - 55% hereditary linkage was evident in the cohort population with 31% - 53 % related to the sensory form of presbycusis for hearing loss in the low or mid frequencies. In addition, 25% - 46% of the hereditability was caused by the strial form of presbycusis. Familial hereditability for women also was relatively high for sisters (53%), mother-daughters (36%), and siblings (53%) (Gates et al., 1999; Gates & Mills, 2005; DeStefano, et al., 2003), indicating a genetic etiology for strial presbycusis in this female population (Gates et al., 1999).

Another important consideration related to age-related hearing loss is its prevalence. Hearing loss is one of the most common chronic conditions in the elderly population (Adams-Wendling & Pimple, 2008; Cruickshanks, Tweed, Wiley, Klein, Klein, Chappell, Nondahl, & Dalton, 2003; Dalton, Cruickshanks, Klein, Klein, Wiley, & Nondahl, 2003; Gordon-Salant, 2005). Between the years 2000 and 2006, the number of Americans 18 years and older with hearing loss rose from 31.5 million to 37 million (Schoenborn & Heyman, 2008). Statistics provided by the National Institute on Deafness and Other Communication Disorders (NIDCD) in 2008 indicate that 30% of individuals between the ages of 65-74 have age-related hearing loss, and 47% of individuals over 75 years old have age related hearing loss (http://www.nidcd.nih.gov/health/statistics/quick.htm). According to the Centers for Disease Control (CDC), it is estimated that by the year 2030, one out of five Americans will be 65 years or older (http://www.cdc.gov/aging/1/31/09). The prevalence of age-related hearing loss and the growing number of older Americans will create an even greater need for hearing related services in the geriatric population.

(Central) Auditory Processing Abilities in Older Adults

Defining (Central) Auditory Processing

(*Central*) *auditory processing*, as defined by the *American Speech-Language Hearing Association* (*ASHA*) *Working Group on Auditory Processing*, refers to the "efficiency and effectiveness in which the central nervous system (CNS) utilizes auditory information" (ASHA, 2005, p. 2). This is a broad statement generalizing the way in which the auditory system processes auditory information. It is more narrowly defined by the ASHA Working Group (2005) to include the "perceptual processing of auditory information" (p. 2) through neurobiological and electrophysiological mechanisms. Consensus in terminology has not been achieved; auditory processing is also known as central auditory processing (Bellis, 2003). Regardless of the terminology used, underlying mechanisms and anatomical locations contributing to auditory processing allows for "sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition, including temporal integration, temporal discrimination (e.g., temporal gap detection), temporal ordering and temporal masking; auditory performance in competing acoustic signals (including dichotic listening); and auditory performance with degraded acoustic signals" (ASHA, 2005, p. 2). (Central) auditory processing deficits in any of these processes may additionally impact cognition, language, learning, and communication as well as other higher order processes (ASHA 2005). Each of these processes is described below.

With sound localization or lateralization, the listener uses differences in sound intensity and/or phase of arrival at the two ears to locate sounds in the environment (localization) or to one of two earphones (lateralization). Sound localization tasks are known as binaural interaction tasks because the listener must combine and interpret the differing sound information from the two ears. Binaural interaction tasks also reveal how both ears work together to process timing and intensity acoustical changes in the presence of noise to allow for a release from masking. Binaural interaction abilities can be evaluated using the *masking level difference* (*MLD*) test (ASHA, 2005; Bellis, 2003) or the *Listening in Spatialized Noise-Sentences Test* (Cameron, 2008).

Auditory discrimination requires a listener to determine whether two or more speech or non-speech sounds are different or alike in frequency, intensity, or duration/timing. Word discrimination testing assesses a listener's ability to perceive just-noticeable acoustic changes such as in frequency and intensity (ASHA, 2005; Bellis, 2003). The most commonly used assessments of word discrimination technically do not directly evaluate discrimination because the task involves word recognition, rather than discrimination (i.e., a same or different task).

Auditory pattern recognition refers to how a person perceives acoustical changes over time (ASHA, 2005). In auditory pattern recognition, listeners typically hear a pattern of two or more tones that differ in frequency, intensity, or duration and are asked to identify the pattern. A three tone pattern differing in frequency, for example, might be reported as high, high, low. Auditory pattern recognition has been related to the ability to perceive the prosodic or intonation aspects of speech as well as hemispheric communication by modifying the response mode required of the listener.

Temporal processing ability most commonly examined is temporal resolution which requires the listener to detect a rapid change in one or more sounds (e.g., gap detection). Another temporal processing ability that might be evaluated is temporal masking, in which a masker either slightly precedes or follows a target sound.

Performance with degraded acoustic signals typically involves the identification of words that are degraded by filtering, background noise, or time compression. Listening tasks using degraded words are presented monaurally (one ear at a time) and are also known as “auditory closure” or “auditory figure/ground” tasks (Bellis, 2003, p. 213, 218).

Performance with competing signals refers to dichotic listening involving presentations of different acoustic stimuli to the two ears either simultaneously or nearly simultaneously. The listener may be asked to identify the message from one ear (i.e., a binaural separation or selective attention task) or from both ears (i.e., a binaural integration or divided attention task).

Flow of auditory information.

The flow of auditory information is a redundant process beginning at the periphery, with multiple pathways through the brainstem and temporal lobes and ending at the cerebral cortex (Yalcinkaya & Keith, 2008). This redundant flow of information is disseminated through both ascending bottom-up and descending top-down processing pathways. Bottom-up processing reflects the sensory processing of the signal (“input”) from lower to higher levels in the nervous system whereas top-down processing reflects the influence of higher level cognitive or language-related knowledge and skills on sensory perception and interpretation (Bellis, 2002; p. 329). Bellis also indicates that top-down processing includes concept driven processing related to attention, memory, cognition, and language, all of which ultimately affect the understanding of speech. According to Owens (2001), bottom-up processes include the encoding of acoustic and linguistic information; it is a "data driven processing where analysis is at the level of sound/syllable discrimination and progresses up to higher ordered levels" (p.124), whereas top-down processing is conceptually driven and is reliant upon the listener's expectations regarding the information being received. Bottom up and top down processing are interactive with identification of acoustic signals within the environment as well as higher-order contextual and conceptual dynamics providing the listener with cues needed to recognize and accurately process auditory stimuli (Craik, 2007). Bottom-up and top-down processing systems function concurrently; a deficit in one system may affect the other system (Craik, 2007).

(Central) auditory processing deficits may be observed with normal peripheral auditory function and normal hearing or may co-occur with peripheral auditory deficits. A degraded auditory signal may occur with pathologies in the outer, middle, or inner ear (e.g., impacted cerumen, middle ear fluid, cochlear hearing loss) and can result in missed or misperceived sounds, words, and phrases. Neurological diseases such as Multiple Sclerosis, Parkinson's, or cardiac infarct may further impede the processing of auditory information within the central auditory nervous system (Bamiou & Luxon, 2008).

As central auditory processing deficit often has an impact on academic functioning in school aged individuals, research in this area has mainly focused on children, and young adults (Bamiou & Luxon, 2008; Jerger & Musiek, 2000; Jirsa, 2001; Yalcinkaya & Keith, 2008). There is, however, a growing body of research that has identified presence of central auditory processing deficits in middle aged and the elderly (Cox, McCoy, Tun, & Wingfield, 2008; Golding, Taylor, Cupples, & Mitchell, 2006; Humes, 2005; Martin & Jerger, 2005; Neijenhuis, Tschur, & Snik, 2004). More research in the elderly population is needed in order to establish a comprehensive universal test battery, to determine the effects of age related peripheral and central changes on the speech perception and auditory processing abilities of the elderly, and implement (re)habilitative management strategies for use with the elderly population.

Central auditory processing test battery.

One of the most challenging issues facing researchers studying (central) auditory processing in the elderly population is the lack of a uniform test battery. There are several commercialized screening and/or test batteries available. However, variables such as differences in procedural administration, lack of data on test specificity, and sensitivity are all contributing factors for the lack of a specific gold standard test battery (ASHA, 2005). Tests can be administered monaurally or binaurally, use speech or non-speech stimuli, have varying degrees of task complexity, and can require different response modes such as open or closed-set tasks. As summarized by Stach (2000) (in Roeser et al., 2000), due to peripheral deficits as well as biological aging processes within the central auditory systems, the elderly population often performs poorly on (central) auditory processing tests (i.e., filtered/time altered speech, non-sense dichotic syllables and making level difference). Pichora-Fuller (2003) indicated that reduced speech perception abilities may be due to deficits in processing monaurally and binaurally presented stimuli. Another complicating situation is the existence of many different tests designed to evaluate the same processing area.

Despite many obstacles, professionals continue to develop test batteries and protocols to use for assessment of (central) auditory processing. Stach's (2000) rationale for including tests in a battery is based on selection of tests that have been validated for use with patients who are diagnosed with neurological deficit, measures that can be used on most patients that are clinically efficient, measures with reasonable specificity and effective control over confounding factors like hearing sensitivity, and a patient's cognition. Thus, his approach incorporates a rationale for controlling for influences relative to hearing sensitivity, speech recognition and supramodal factors such as language and cognition. Therefore, Stach proposed an (central) auditory processing test battery approach that uses: 1) word recognition testing in quiet to measure a performance-intensity function across different intensity levels; 2) *Synthetic Sentence Identification* (*SSI-ICM*) presented monaurally; and 3) *Dichotic Sentence Identification* (*DSI*). According to Stach, these tests along with middle ear analysis using tympanometry and acoustic reflex tests, outer hair cell function assessment using otoacoustic emissions and auditory evoked potentials can be beneficial in the diagnosis of an auditory processing deficit. Stach's approach is one of many reported in the literature; another test battery is offered by the American Speech Language and Hearing Association (ASHA).

As previously stated, there is no universal auditory processing test battery. However, the ASHA Working Group on Auditory Processing Disorders (2005) recommends a (central) auditory processing test battery that includes verbal and nonverbal stimuli and assessments of the peripheral, neural, and central auditory structures. They recommended that the minimal test battery should include: 1. auditory *discrimination tests*; 2. auditory *temporal processing/patterning tests*; 3. *dichotic speech tests*; 4. *monaural-low redundancy (performance with degraded materials) tests*; 5. *binaural interaction* tests; 6. *electroacoustic analysis*; and 7. *electrophysiology measures*.

As peripheral auditory deficits can impact central processing, it is imperative to test the integrity of the outer, middle, and inner ears prior to conducting (central) auditory processing tests. Specific testing includes: tests to indicate peripheral deficits in the auditory system such as auditory threshold testing, electroacoustic measures such as middle ear analysis and otoacoustic emissions, and word recognition tests. Middle ear measures such as tympanometry and acoustic reflex threshold testing provide information regarding transfer of acoustic information from the outer and middle ear into the inner ear. Otoacoustic emission testing is conducted for objective measurement relative to function of the outer hair cells within the cochlea. It should be noted that most tests of (central) auditory processing do not offer normative data for individuals with hearing loss.

Typically, central auditory testing includes temporal processing and temporal patterning tests using tonal and speech stimuli, dichotic speech tests using numbers, words and/or sentences, monaural low-redundancy tests using words that have been acoustically altered (i.e., filtered or with changes in timing or intensity), and binaural interaction tests using masking noise with tonal or speech stimuli (ASHA, 2005). The most commonly used measures are: *Random Gap Detection Test (RGDT)* (Keith, 2000) for temporal resolution, *Dichotic Digits (DD)* (single or double digits) Test (Musiek, 1983) for binaural separation/integration, *Low-Passed Filtered Speech* Test using NU-6 words (Tonal and Speech Materials for Auditory Perceptual Assessment Compact Disc, 1992) for monaural low-redundancy speech assessment, and the *Masking Level Difference (MLD)* (Wilson, Zizz, & Sperry, 1994) using speech material for binaural interaction (ASHA, 2005; Bellis, 2003). Electrophysiological testing using auditory brainstem response (ABR), middle latency response (MLR), and late latency response (LLR) measures can provide further indication of auditory thresholds, confirm or rule out neural disorders, and indicate neural changes occurring throughout the central auditory system (ASHA, 2005). However, electrophysiological testing is not routinely used most likely due to the additional time, equipment, and questionable reimbursement for such measures.

Effects of hearing loss and aging on (central) auditory processing.

Central auditory processing deficits are reported to occur in about 50% of adults, ages 51to 91 years old (Jerger, Jerger, Oliver, & Pirozzolo, 1989). Lesner (2003) noted reports of prevalence ranging from 58% to 95% for adults ages 65 to 80 years. Even with presentation level adjustments, mild to moderate hearing loss can affect (central) auditory processing test results related to performance with competing signals (dichotic digits), temporal patterning (pitch patterns), performance with degraded acoustic signals (low pass filtered speech, words in noise), and binaural interaction (binaural fusion) (Neijenhuis, Tschur, & Snik, 2004). Neijenhuis et al. noted that other researchers such as Speaks, Niccum and Van Tasell (1995), Musiek and Pinheiro (1987), and Musiek, Baran and Pinheiro (1990) had found minimal impact on dichotic and pitch pattern test results for those with mild hearing loss. However, other researchers including Cox, McCoy, Tun and Wingfield (2008) and Humes (2005) used participants with various configurations of hearing loss while Neijenhuis et al. (2004) only included participants with a flat configuration of hearing loss. Neijenhuis et al. did note that performance on one degraded speech test (sentences in noise) was within the normal range for mildly hearing impaired individuals when presentation level was raised. There have been other reports that some sentence level materials may not be negatively impacted if materials are presented at a sufficient intensity level (Golding, Taylor, Cupples & Mitchell, 2006).

Cox, McCoy, Tun and Wingfield (2008) used a monaural auditory processing test battery to examine whether differing degrees of peripheral hearing loss and cognitive abilities affected test results in the elderly. Participants were divided into three groups of 15 per group, one group with normal hearing from 500-4000 Hz, a second group with high-frequency sloping hearing loss from 2000-8000 Hz, and a third group with low and high frequency hearing loss across the range of 250-8000 Hz. Cognitive testing included assessment of working memory *(Forward and*

Backward Word Span Test; Weschler, 1981), processing speed (*Digit Substitution Subscale of the Weschler Adult Intelligence Scale-Revised*; Weschler, 1981) and executive functioning and attention (*Trail Making Test;* Reitan, 1958; 1992). Auditory processing assessment included *Low-Pass Filtered Speech* (Auditec of St. Louis), *Pitch Pattern Sequence Test* (Auditec of St. Louis), the *Quick Speech in Noise Test* (Etymotic Research), *Synthetic Sentence Identification Test-Ipislateral Competing Message* (Auditec of St. Louis), *NU-6 Time Compressed Speech Test* (Auditec of St. Louis), and the *Random Gap Detection Test* (Keith, 2001; Auditec of St. Louis). In general, age was not a significant predictor of auditory processing performance except for performance on Pitch Pattern Sequence a test of temporal patterning. This result is consistent with other temporal processing test results in the elderly population in that age-related declines are also apparent on gap-detection, duration discrimination, and identification of time compressed speech stimuli, and acoustic temporal speech cues such as manner of consonant articulation (Chisolm et al., 2003; Gordon Salant and Yeni-Komshian, Fitzgibbons, & Barrett, 2006; Gordon Salant, 2005; Martin & Jerger, 2005; Mazelova et al., 2003; Pichora-Fuller & Souza, 2003). Cox et al. (2008) found no significant relationship between high-frequency hearing loss and auditory processing performance. Low frequency hearing loss was related to poorer performance on time-compressed speech measures. The influence of cognitive abilities on auditory processing performance was minimal as assessed by working memory, processing speed, and executive functioning/attention.

In a study to measure the possible association between cognition and auditory processing in the elderly population, Humes (2005) recruited 213 participants aged 60-88 with binaural sloping mild-to-severe sensorineural hearing loss. Testing consisted of audiometric thresholds for pure tones and speech, immittance testing, performance intensity-function for rollover calculation, measures of auditory brainstem response (ABR) for a 2000 Hz click at slow and fast rates, and the *Weschler Adult Intelligence Scale-Revised* (*WAIS-R*; which includes measures of verbal, nonverbal, and total IQ). Humes used two auditory processing tests of duration discrimination and tonal temporal order discrimination from the *Test of Basic Auditory Capabilities* (*TBAC*) (Christopherson & Humes, 1992) and two auditory processing tests of dichotic consonant-vowel (CV) identification and 45%-time-compressed word recognition from the Veterans Administration Compact Disk for Tonal and Speech Materials for Auditory Perception (VACD) (Humes, Coughlin, & Talley, 1996). Results from this study indicated that age and cognitive function were two factors contributing to performance on the auditory processing tasks of duration discrimination, temporal order discrimination, and dichotic CV discrimination. Auditory processing performance on these tasks was more directly associated with cognitive function than degree of hearing loss. On these tasks, scores improved as IQ increased and age decreased. For the auditory processing task involving time-compressed speech, more of the variance in scores was related to high-frequency pure tone average than to the other predictor variables (i.e., age, IQ and ABR measures).

Speech Perceptual Abilities in Older Adults

Introduction

Human speech perceptual abilities have been extensively investigated since the 1940's with the development of the *Articulation Index* (*AI*) (Kidd, Watson, & Gygi, 2007). This index has been used as a means to measure the audibility of the speech spectrum or proportion of speech that is available to an individual listener (Roeser, Valente, & Hosford-Dunn, 2000). Clinically, the AI is rarely used and has been replaced by other measures, such as speech recognition threshold (SRT) and word recognition (WR) tests, that are used for the purpose of gauging speech perceptual abilities. In addition, updated interpretative tools such as the "*Speech Recognition Interpretation* (*SPRINT*)" chart (Thibodeau, 2000) with normative data from Thornton and Raffin (1978) and Dubno et al. (1995), and the performance intensity (PI) function with calculation of rollover can be used for the interpretation of speech recognition abilities (Roeser et al., 2000).

Stach (2003) provides a formal definition of speech perception as including auditory skills such as; "awareness, recognition, and interpretation of speech signals received in the brain."(p. 206). In addition, Tye-Murray (2004) highlights the importance of acoustic cues, environmental factors, and cognitive abilities on the perception of speech. Acoustic cues refer to the frequency, intensity, and durational characteristics of speech. Environmental factors that impact speech perception may include conditions within a listening situation, such as "elevated background noise and dimly lit rooms" (p.47-48). Cognitive influences in older adults result from "slowed processing speed and reduction in working memory" (p.514). Reduced acoustic cues and/or cognitive function may add to difficulties related to hearing loss and cause further difficulties with speech perception.

Speech perception in the elderly population.

One common complaint from the elderly population is the statement, "I can hear people talk but I can't understand what they say" (Tye-Murray, 2004, p. 404). This typically occurs when the older listener is in an adverse listening environment (Gordon-Salant, 2005; Helfer & Freyman, 2008; Divenyi, Stark, & Haupt, 2005). To understand this effect, a working group known as the "*Committee on Hearing, Bioacoustics and Biomechanics* (*CHABA*)" (1977, 1988) convened to review existing research on "speech understanding" as well as the biological and functional aging aspects of the auditory system (Working Group on Speech Understanding and

Aging, 1988). The CHABA (1988) reported that short term payoffs in reducing hearing handicap would be achieved with management related to hearing aid technology, aural rehabilitation, and hearing conservation. Furthermore, long-term payoffs could be achieved by gaining a better understanding of the structure and function of the auditory system and how the aging process leads to degraded speech perceptual abilities. The CHABA also presented the following three possible sources of age-related declines in speech understanding: 1) peripheral auditory system, 2) central auditory system, and the 3) cognitive processing system. There may be contributions from all three of the above mentioned processing systems (Humes, 1996).

Research with humans and animals, as well as histological studies, provide empirical evidence that the inner ear and central auditory system are critical for speech perception (Chisolm, Willott, & Lister, 2003; Gates & Mills, 2005; Seidman, Ahmad, & Bai, 2002). Functional damage, as reported by CHABA (1988), occurs as a result of intrinsic insult such as natural physiological degeneration or from extrinsic insults such as disease or trauma. These degenerative factors can impact peripheral and central components of the auditory system. As a result, intrinsic and extrinsic redundancy of the auditory system may be altered leading to an inability to effectively perceive speech. Therefore, structural or functional breakdowns as well as age-related factors may lead to increased difficulty with speech perception. One aspect of processing that has been consistently related to speech perceptual abilities in the elderly is auditory temporal processing which will be further discussed.

Temporal processing.

Temporal processing relates to the perception of time-varying sounds (Moore, 2004). There are two main listening tasks or abilities associated with temporal processing that contribute to human speech perceptual abilities. One ability is that of temporal resolution which refers to perception of timing or interval changes in speech and non-speech stimuli (Bellis, 2003; Stach, 2003). Examples of temporal resolution include the ability to identify the difference in voice onset time of syllables (i.e., /t/ vs. /d/) and words (i.e., boat vs. boast) (Bellis, 2003; Pichora-Fuller & Sousza, 2003) and discrimination of differences in tonal stimuli varying in duration or interval duration between tones (Karmarkar & Buonomano, 2003). Temporal resolution facilitates speech perception in everyday listening environments, especially in situations when noise and reverberation are present (Gordon-Salant, 2005; Pichora-Fuller & Souza, 2003).

The second listening ability associated with temporal processing is the processing of spectral information within sounds over time, to include fundamental frequency (i.e., pitch) and harmonic structures of complex sounds (Moore, 2004; Robin, Tranel, & Damasio, 1990). Relative to speech perception, spectral resolution is used for perception of speech cues with varying acoustic energy across frequency domain, such as consonants, vowels, and diphthongs (i.e., formants) (Van Riper & Erickson, 1996). There are several examples of spectral resolution tasks. One example is the ability to recognize the pitch or fundamental frequency (Robin, Tranel, & Damasio, 1990) of a speaker's voice when speech is distorted as is the case for time-compressed speech (Gordon-Salant, 2005). A second example would be recognition of speech presented in quiet as well as speech presented monaurally, as these elements rely heavily on the audibility of the speech signal in the spectral domain (Pichora-Fuller & Sousza, 2003). A third example of spectral resolution would be the ability to perceive complex harmonic tones, such as timbre between successive tones (Moore, 2004). Research using tonal, musical, and interrupted and continuous noise stimuli has explored whether temporal resolution abilities such as temporal discrimination and spectral resolution influences human speech perception in adults (Karmarkar

& Buonomano, 2003; Russo & Pichora-Fuller, 2008; Stuart & Phillips, 1996), children, and young adults (Stuart, Givens, Walker, & Elangovan, 2006). As mentioned in Pichora-Fuller and Souza (2003), age-related temporal processing problems can lead to speech perception difficulties especially when listening in settings with background noise.

Some research conducted with only young normal hearing listeners may offer evidence of other factors that may be important when listening to speech in noise. Kidd, Watson, and Gygi (2007) proposed that speech recognition ability is independent of temporal and spectral discrimination of tones. Using 19 different auditory subtests comprised of a variety of materials (i.e., speech, tones, noise, and environmental sounds), Kidd et al. evaluated the auditory discrimination and identification abilities of 340 young normal hearing adults. Results indicated considerable variance in scores on subtests, suggesting a wide range of abilities among participants. In order to determine whether intellectual abilities influenced the variance observed, a correlation analysis was run to compare *Scholastic Aptitude Test* (*SAT*) (The College Board, 2010) (http://en.wikipedia.org/wiki/College_Board, 2009) scores with variance scores. Analyses showed that verbal and math abilities only minimally influenced performance for familiar sounds recognition and pitch/time tests. Investigators concluded that general intelligence, as indicated by SAT scores, had little to no effect on auditory discrimination or identification abilities. One major outcome of this study was classification of all auditory abilities tested into four factors. Factor one, loudness-duration discrimination reflected all subtests with intensity and durational changes in energy. Factor two, amplitude modulation detection, refers to the ability to perceptually discriminate sounds, based on changes of acoustical modulation rate and amplitude. Factor three was familiar sounds recognition (FSR), an ability to use familiar sound cues to facilitate listening. The following three underlying components of FSR were proposed by Kidd, Watson, and Gygi (2007): 1. activation of stored information (i.e., memory) for speech and environmental sounds; 2. auditory closure strategies in order to fill in missing pieces for signals that are not complete; and 3. effective attention for located spectro-temporal information within the familiar sound. The fourth factor was spectral and temporal pattern discrimination. This ability relates to recognition of the overall pattern of the sound and encompasses frequency and timing as a means of holistically discriminating sound quality changes. Kidd et al. suggested that the FSR ability plays a significant role in speech perception in noise in this young normal hearing sample. This is of interest as difficulty with speech perception in adverse listening conditions has been predominately attributed to temporal resolution deficits. However, as suggested by Kidd et al., an individual's inability to utilize FSR processing strategies may be one underlying factor in speech perceptual deficits.

Degraded temporal or spectral processing abilities in older adults may be influencing their speech recognition skills (Kidd et al., 2007; Tremblay, Piskosz & Sousza, 2003). Electrophysiological and behavioral research conducted by Tremblay, Piskosz, and Sousza (2003) using syllables differing in *voice onset time* (*VOT*) supports the idea that temporal properties are affected by age-related hearing loss. VOT refers to the interval of time between the release of articulation for a consonant and the beginning of voicing (Kent, 1997; Tremblay et al., 2003). In Tremblay et al. measures of the N1-P2 complex of the cortical late-evoked potential were used to examine the neural response to /ba/-/pa/ stimuli varying in VOT. Behavioral measures also were obtained in which stimuli were presented through earphones with participants identifying whether two syllable tokens were the same or different. Thirty participants were divided into three groups: ten young normal-hearing adults ranging in age from 19-32, ten older normal-hearing adults ranging in age from 61-79, and ten older adults with high frequency sensorineural hearing loss ranging in age from 60-81. The stimuli were presented monaurally to the right ear and consisted of a seven-step synthesized VOT token along the /ba-pa/ continuum ranging in VOT from 0 to 60 ms. Tremblay et al. (2003) obtained behavioral VOT data via a discrimination task in which participants were asked to listen to token pairs and determine if stimuli were the same or different. Analysis of behavioral results indicated that the older participants demonstrated more difficulty with discriminating a VOT difference of 10 ms between syllables (e.g., syllable one VOT of 30 ms and syllable two VOT of 40 ms), unlike younger participants. In addition, a significant age effect was evident as the younger participants' performance was significantly better than both groups of older listeners (i.e., normal hearing and hearing impaired). Furthermore, when comparing the two older groups, the group with hearing loss performed more poorly than the normal-hearing older group. Results from the electrophysiological data indicated that all three groups had: 1) prolonged P1, N1 and P2 latencies with increases in VOT; 2) the older group with hearing loss demonstrated prolonged N1 latencies relative to VOT durations > 20 ms, while the older normal hearing group demonstrated prolonged N1 latencies relative to VOT durations > than 30 ms and 60 ms; 3) compared with the younger group, both older groups had delayed P2 latencies for all VOT stimuli; and 4) compared to the young and older normal hearing groups, the older group with high-frequency hearing loss had larger N1 amplitudes relative to the 60 ms VOT syllable. The investigators stated that their behavioral results coincide with other empirical research that indicates older adults have more difficulty perceiving temporal cues. Temporal processing relies on neural processing of time-variations of an acoustic signal and aging affects both neuronal and behavioral processing of speech. Therefore, both neuronal and behavioral factors are thought to be contributors in perceptual deficits of temporal processing (Tremblay et al., 2003). Neuronal processes may be affected by aging and negatively impact processing of speech in the elderly. Furthermore, the aging auditory system coupled with hearing loss in the older adult leads to difficulty with discrimination of speech cues as well as diminished synchronous neural firing as evident from behavioral and cortical responses to VOT contrasts. Therefore, age-related changes occurring in the peripheral and central auditory systems all appear to play a role in speech perception deficits in the elderly population.

As stated previously, one of the most common complaints of older adults with hearing loss relates to their listening difficulties in settings with background noise. Russo and Pichora-Fuller (2008) studied how different types of background noise (i.e., familiar music, unfamiliar music, and multi-talker-babble) affected younger and older adults' ability to identify speech. These investigators recruited young normal hearing individuals ranging in age from 18-30 and older normal hearing individuals ranging in age from 65-80 to participate in their study. Individuals in the younger and older groups first listened to a wide range of instrumental music to establish musical passages that were familiar and unfamiliar. The investigators conducted two separate experiments to assess word identification abilities with the three different background noises. The first experiment was conducted to determine overall accuracy of word identification in the three types of background noise. In the second experiment, memory of background music presented was assessed to determine whether conscious processing of the background music played a role in word identification. Results indicated that the older individuals processed music and talker-babble differently than younger normal hearing adults. These investigators determined that 1. older adults' performance on word recognition tasks was not affected differentially by type of background competition while younger adults demonstrated better word identification scores when background music was familiar; 2. older adults were poorer at remembering background music presented during the task as compared to younger adults; and 3. older adults had higher false alarm rates for identification of familiar music than unfamiliar music. When listening to familiar music, younger adults appeared to consciously change their focus to familiar music which in turn created a *release from masking* effect (or ability to perceptually improve processing of a signal that occurs with some types of masking signals). This release from masking effect afforded the younger adults opportunity for enhanced perceptual separation between speech and familiar music.

Stuart and Phillips (1996) investigated effects of interrupted and continuous noise on speech recognition in younger and older adults. Investigators included three groups of participants representing young normal hearing individuals with a mean age of 24.9, older normal hearing individuals with a mean age of 61.0 and older hearing impaired individuals with a mean age of 62.8 years. Stuart and Phillips reported that word recognition scores in both noise conditions were poorer for older adults with normal hearing and older adults with presbycusic hearing loss when compared to performance of younger normal hearing listeners. They also indicated that all participants demonstrated release from masking abilities as evidenced by better performance in the interrupted noise condition. Although performance was superior for the interrupted noise condition compared with the continuous noise condition, the presbycusis group demonstrated significantly poorer speech perceptual abilities in the interrupted noise condition relative to the young normal hearing and older normal hearing groups. Thus, Stuart and Phillips (1996) concluded that older adults with hearing loss exhibit temporal processing deficits. The data showing poor speech recognition for older participants with hearing loss most likely reflects the loss of auditory sensitivity in the basal portion of the cochlea as well as to diminished temporal resolving abilities as a result of broadening auditory filters (Moore, 2004).

Recent research by Helfer and Freyman (2008) has provided more information relative to speech perception abilities particularly for speech-on-speech masking and its' effect in the geriatric population. Helfer and Freyman (2008) conducted a study to examine how much difficulty older people have with speech perception especially when in the presence of competing speech. In particular, these researchers wanted to determine how much an older listener's speech perception was affected by such factors as; "energetic masking", "informational masking" and cognition (i.e. "higher-level" processing that enables a person to "ignore the masker") (p. 88). Energetic masking occurs at the spectro-temporal level of the auditory periphery and refers to energy within a masker noise (i.e., speech or non-speech) that is greater than the energy of a target speech signal and that is sufficient enough to cover up the speech signal (Barker & Cooke, 2006; Helfer & Freyman, 2008). Informational masking occurs in the central auditory system and refers to speech target and speech masker competition such that the listener is unable to tease out one signal from the other (i.e., single voice vs. multi-talker speech competition) (Barker & Cooke, 2006; Helfer & Freyman, 2008), resulting in both signals being camouflaged (Russo & Pichora-Fuller, 2008). Helfer and Freyman (2008) also wanted to examine if participants could learn to differentiate between the target voice and the masker voice(s), as to potentially help a listener understand the target voice better when other voices were present. These researchers hypothesized that older listeners would perform poorer than younger listeners when listening to one female speaker recite sentences in the presence of different maskers such as, female two-talker babble (FTT), male two-talker babble (MTT), signal-envelope-modulated noise (SEM) and a speech-shaped noise (SSN) masker. A second factor explored was related to the benefit of topic knowledge for identifying sentences in noise. Helfer and Freyman hypothesized that poorer speech recognition in older adults may be related to a reduction of temporal gap ability, poor selective attention abilities, and an inability to ignore the masker (i.e., informational masking). Twelve normal hearing college aged participants with a mean age of 22.6 and twelve older normal hearing participants with a mean age of 71.5 participated in this study. During testing, participants were seated in a sound-isolated test booth with target speech and noises presented in the sound field conditions described below. Participants listened to a target female speaker reciting sentences in the presence of the various maskers (i.e., described above). In the first experiment, participants listened to and recited sentences that were presented in three different types of background noise (i.e., female two-talker babble, male two-talker babble and signal-envelope-modulated noise) at four different signal-to-noise ratios (i.e., -8, -4, 0, and +4) and under two different spatial conditions (i.e., target speech front/noise front and target speech front/noise at 60° azimuth) for a total of 24 listening conditions. In the second experiment, participants listened to two sentence sets, one with and one without topic, at a -8 signal-to-noise ratio with speech-shaped noise and target sentences and noise both from a front loudspeaker. This task was used to determine whether semantic information (i.e., topic) assisted older listeners' performance more than younger listeners. The third experiment consisted of a voice discrimination task to determine if listeners could differentiate a female target speaker's voice from other female masker voices. As mentioned by the investigators, learning to differentiate the target speaker's voice from the masker voice may help individuals comprehend the target voice when in the presence of multiple speakers. Overall, results supported the investigators' main hypothesis that the older group performed poorer on speech identification than the younger group for all listening conditions. In addition, differences in speech perception varied for the groups based on type and amount of masking presented. Both groups showed the same benefit from adding topical information to the sentence in noise task. Thus, older and younger groups were "able to use topic knowledge to the same extent for speech recognition in a steady state noise" (p. 93). On the voice discrimination task, there was a statistically significant difference with the older group performing more poorly than the younger group. However, both groups had difficulty in discriminating same sex talkers and therefore, similar voices in real world conditions would be expected to be difficult to sort out. Using data from the SNR conditions of -8, -4, and 0 in the older group, a correlation analysis to determine if age, hearing loss, and test performance were related, revealed a significant negative correlation with degree of high-frequency hearing loss (i.e., average of better ear thresholds at 2, 3, 4 and 6 kHz). In contrast, age was not significantly correlated with speech recognition abilities in this group of older adults.

Speech perception abilities in older adults are hampered by a number of factors including environment, hearing loss, cognition, aging, and deficits in spectral and temporal resolution (Pichora-Fuller & Souza, 2003). When considering the numerous biological, physiological, and extrinsic factors that can contribute to difficulty with speech perception, it is important to keep in mind that auditory deficits may arise from several anatomical locations within the auditory system. Furthermore, these auditory deficits may be concomitant with age related changes in the peripheral and central auditory systems and may also be associated with cognitive changes related to aging, that collectively impact speech recognition in older adults.

Cognitive Abilities in Older Adults

Definition of Cognition

Cognition has been defined as "the processes involved in knowing, including perceiving, recognizing, conceiving, judging, sensing, and reasoning" (Stach, 2003, p. 59). It is well accepted that cognitive changes occur as one ages (Eckert, Walczak, Ahlstrom, et al., 2008;

Kricos, 2006; McCoy, Tun, Cox, et al., 2005; Pichora-Fuller, 2003; Salthouse, 1998). When peripheral and/or central neural changes occur in the brain due to aging or disease processes (i.e., stroke, multiple-sclerosis, aphasia, dementia, Alzheimer); these changes may compromise transmission of the signal through the brain leading to a breakdown in perceptual and cognitive abilities. Cognition includes many areas of higher order functioning such as memory, attention, processing speed, and language which collectively aid in speech comprehension. Although hearing loss negatively impacts speech perception, Wingfield, Tun, and McCoy (2005), and Pichora-Fuller (2003) reported that linguistic knowledge is one area relatively un-affected by aging as older individuals can utilize recall stored in long term memory to compensate for sensory loss as well as deficits in working memory (a component of short-term memory). In other words, the brain uses higher order cognitive processing as a means of deciphering the incoming signal into a meaningful message. Memory, attention, and processing speed will be discussed in the following sections.

Memory.

Research interest in memory was established sixty years ago with Hebb (1949) who described a “unitary” “*short-term memory*” (*STM*) system functioning as a result of “temporary electrical activation” and a “unitary” “*long-term memory*” (*LTM*) system functioning due to “neuronal growth” (Baddeley, 2003, p. 830). According to Just and Carpenter (1992), STM is a “storage device” that allows a person to hold information in the system prior to recalling the information, while LTM uses STM as a “stepping stone” that allows for the recall of memorized information learned through “rehearsal” (p. 122). The concept of *working memory* (*WM*) is relatively newer. Working memory has been defined recently by Wingfield et al. (2005) as “the ability to temporarily hold and manipulate information in active use” (p. 144). When examining

STM only, a listener might be asked to report digits remembered from a list of digits. In contrast, a WM task integrates STM ("recent information") and LTM ("stored knowledge") requiring one to "manipulate" the information, and setting the stage for more complicated processing such as speech perception (Pichora-Fuller, 2003, p. S29; Pichora-Fuller & Singh, 2006, p. 49). An example of a working memory task would be the *Numbers Reversed Test* (Mather & Woodcock, 2001; Schrank, McGrew, & Woodcock, 2001) where a string of numbers are presented orally and the task is to repeat the string of numbers backwards (i.e., 1, 5, 7, 9, would be repeated as; 9, 7, 5, 1).

In 1974, Baddeley and Hitch proposed a working memory (WM) model that moved away from the previously described "unitary" model to a model that incorporated three functional processes within the WM mechanism known as the; "central executive", "phonological loop", and "visouspatial sketchpad" (Baddeley & Hitch, 1994, p. 485). The nature of the working memory model is very complex and involves interactions between multi-sensory and multi-cognitive systems (Baddeley, 2000) which have been studied in animal and human experiments in many disciplines including; cognitive and developmental psychology, neuropsychology, neuroimaging, and computational modeling (Baddeley, 2000, 2003; Itti & Koch, 2001; Just & Carpenter, 1992, Rabbitt, Scott, Thacker, et al., 2006; Wrigley & Brown, 2004).

The following discussion will briefly address the central executive, phonological loop, and a newer component to the model, the episodic buffer (i.e., whereas the visuospatial sketchpad, a key factor in visual processing, will not be addressed). The central executive (Wingfield et al., 2005) refers to the WM structure that "organizes and coordinates multiple mental operations to be performed" (p. 144). Due to the anatomical complexity of the human brain, the central executive component is not well understood; however, is thought to be located in the frontal lobe region (Baddeley, 2000). The central executive is a mechanism capable of coordinating multiple sub-processes (Baddeley & Hitch 1994) as an attentional control system (Baddeley, 2000). The central executive is functionally different from the phonological loop and visuospatial sketchpad in that it is considered the control system for processing of verbal and visual information for all of WM (Baddeley, 2003).

The phonological loop is a sub-compartment of WM that is responsible for retaining and manipulating speech information. Anatomically, the phonological loop is correlated with Brodmann areas 40 and 44 in the parietal and frontal lobes, respectively (Baddeley, 2003). Within the phonological loop, lays the memory trace which is an area where phonological and/or acoustical information processing occurs (Baddeley & Hitch, 1994). At this stage, the information passing through the memory trace will quickly fade from memory (in ~ 2 s), unless there is some form of subvocal rehearsal (Baddeley & Hitch, 1994). The memory trace is an important aspect of the phonological loop as individuals presenting with cognitive problems may have a greater deficit as a result of poor WM.

Recently, Baddeley (2000; 2003) reported on problems associated with the 1974 WM model and has proposed an additional element involved in the working memory process known as the episodic buffer. The inherent problems of the original WM model that became evident with further investigation, brought to light limitations of the phonological loop, visual sketchpad, and central executive specifically related to the lack of a mechanism for conscious awareness and the capacity of such a mechanism to interact with other components. As described by Baddeley (2000; 2003), the episodic buffer refers to binding of information from the multiple sub components of WM into integrated episodes. Integrated information is held in such a way that allows for preservation of the information across time. Based on evidence from neuroimaging studies, Baddeley (2000) hypothesizes the biological mechanism underlying the episodic buffer as being synchronous firing. Furthermore, he reports that although the frontal lobes are important, there are more than likely several anatomical locations for the central executive and its' episodic buffer element. This fourth component of the WM model is thought to be a "limited-capacity storage unit" that is controlled by the central executive. The episodic buffer is a critical element in the WM model as it is thought to be responsible for linking conscious awareness with integrated information from the other sub-components and LTM. In addition, it is assumed that the episodic buffer allows for the transfer of "crystallized knowledge" (i.e., binding of knowledge that builds/changes within LTM) to be retrieved by the "fluid" components of the WM model (i.e., WM units of attention and temporary storage that do not change as a result of learning) (Baddeley, 2000; Baddeley, 2003). The episodic buffer was presented as a separate subsystem for the central executive and is thought to act as its' storage compartment (Baddeley, 2003). The supposition of the episodic buffer as a separate system provides a mechanism for WM to manipulate information to form new representations instead of just activating stored memories (Baddeley, 2003). The addition of the episodic buffer into the WM model has expanded the scope of the original model by providing an avenue to link the multiple-components of the model into a functional compartment capable of consciously coordinating and manipulating information within the system. Baddeley (2000; 2003) indicated the need for future research of the current WM model, and it is undoubtedly a line of research that will continue to evolve in the fields of neuropsychology and beyond. Relative to other areas of cognition, specifically attention, the WM models proposal and establishment of the central executive as the attentional controller (Baddeley, 2000) highlights the importance of attention in cognitive processing. Attention will be discussed in a later section.

Hearing loss and memory.

Although cognition and working memory are topics typically researched in the field of psychology, recent research has included investigation of associations between cognition/working memory and hearing loss, auditory processing, auditory training and brain plasticity (Humes, 2005; McCoy et al., 2005; Pichora-Fuller & Souza, 2003; Sweetow & Henderson Sabes, 2007; Tremblay & Kraus, 2002; Wingfield et al., 2005). Two theories related to speech perception, “normalization” (Wingfield et al., 2005, p. 145) and the “effortfulness hypothesis” (McCoy et al., 2005, p. 23), are important when considering speech perception in older adults with hearing loss.

Normalization refers to one's ability to extract linguistic information from an ever changing stream of speech that differs in pronunciation and accents in order to comprehend spoken language (Wingfield, et al., 2005). Sommers (1996) suggested that normalization is determined by one’s phonemic and cognitive abilities. Research conducted by Sommers (1996) supports the theory of normalization by providing evidence that difficulties in perception of lexically easy and hard words are related to apparent differences in phonemic and cognitive abilities. Lexically easy words are described as words within one’s mental lexicon that are frequently used and do not have a large number of similar sounding words that may confound identification of the easy word (e.g., young and map) (Sommers, 1996). Lexically hard words are words that are not used often and have many similar sounding words that may be used more frequently and therefore confound identification of the hard word (e.g., bud and pad). In three separate experiments, Sommers (1996) investigated the relationship between lexical difficulty of words relative to age (i.e., young versus old participants in experiment one), task complexity (i.e., with and without noise in experiment two), and cognitive load (i.e., single talker versus multiple talkers in experiment three). The participants in the first experiment were 18 young normal hearing adults with a mean age of 19 and 19 older adults with a mean age of 74. Nine of the 19 older adults had normal hearing sensitivity, while the remaining participants in the older group had sensorineural hearing losses ranging from mild-to-moderate at 2000 and 4000 Hz. Easy and hard word stimuli produced by four talkers (two men and two women) were presented to the better hearing ear via headphones at 80 dB SPL while the participant listened in a sound attenuated booth. Participants were asked to write down each word they heard. Results revealed that the young adults had average percent accuracy scores for easy and hard words of 97.8% and 90.1%, respectively, while the older adults' average percent accuracy scores for easy and hard words were 91% and 75.5%, respectively. Thus, the older adults demonstrated significantly more difficulty identifying hard words. These data suggest that deficits in speech perception in older adults are directly linked to age-related declines in ability to identify phonemically similar sound patterns in speech. To further explore the potential involvement of age-related peripheral hearing sensitivity relative to demonstrated lexical difficulty, a correlation analysis was conducted relative to age-related hearing loss and effects of identification of hard words. There was no significant relationship between hearing sensitivity (normal hearing compared to mild high frequency hearing loss) and lexical difficulty. In experiment two, the same methods were used as in experiment one, except the stimuli were presented in noise. Nineteen young normal hearing adults with a mean age of 18 and 20 older adults with a mean age of 72 and with normal hearing sensitivity 250-1500 Hz, sloping to a mild-moderate hearing loss at 2000 and 4000 Hz. Results indicated a decrease in percent accuracy scores for easy and hard words in both groups. The young adults' average scores were 72.8% and 61.6% for easy and hard words, respectively, while older adults' average scores were 69% and 37.5%, respectively. These findings support evidence from experiment one that older listeners' have increased difficulty perceiving lexically hard words. Furthermore, these findings do not identify task difficulty as the sole basis for age related declines in speech perception as identifying lexically hard words was evident in both experiments. The last experiment examined age related differences in identification of easy and hard words spoken by one or multiple talkers. Participants consisted of 22 young adults with a mean age of 19, and 21 older adults with a mean age of 74. Again, hearing sensitivity for participants in experiment three were within the same ranges as those in experiments one and two. Stimuli and methods were identical to those conducted in the first two experiments except presentation of the easy and hard words were by either a single-talker or by multiple-talkers within a test block. For example, one entire test block of words was spoken by one talker, while a second entire test block of words was spoken by ten talkers. Results for average percent accuracy scores for the younger adults in the four conditions were 97.1% for single-talker test blocks with easy words; 91.4% for single-talker with hard words; 94.2% for multi-talker with easy words and 84.8% for multi-talker with hard words. Average percent accuracy scores for the older adults were 89.3% for the single-talker easy words; 77.5% for the single-talker hard words; 84.1% for the multi-talker easy words and 61.6% for the multi-talker hard words. These results demonstrated poorer speech recognition abilities of older adults when listening to words spoken by different speakers. These results may reflect "real-world" listening situations where older adults are not only listening in environments with a barrage of environmental noises; but are also listening to different speakers. Therefore, the results reported by Sommers (1996) support the notion of normalization in that older individuals may need to rely on additional cognitive resources in order to sustain perception and accurately identify speech when in challenging listening situations. In addition, further analyses by Sommers revealed a significant age by lexical difficulty interaction which was found in all three experiments. This interaction reflects a deficit in older individuals relative to their ability to recognize more difficult words, especially when the acoustical parameters of the words change. Although the effects of hearing loss and cognitive factors could not be separated in this study, Sommers stated that both hearing acuity and cognitive function may impact older listeners' ability to recognize lexically hard words.

A second important theory is the Effortfulness Hypothesis as proposed by McCoy and colleagues (2005). They purported that individuals with hearing loss expend extra effort to achieve perceptual success and in that process, deplete other processing resources needed for the encoding of speech content into memory. McCoy et al. (2005) recruited 24 older individuals (ages 66-81 years) with hearing thresholds ranging from the normal range to mild-to-moderate hearing loss range for participation in a memory recall experiment. Participants were divided into two groups of 12 people per group with one group being referred to as the better hearing group and the second group being referred to as the hearing loss group. The better hearing group had mean hearing thresholds ranging from13.8 to 45.8 dB HL at 250-6000 Hz and had pure-tone averages (PTAs) in the better ear of 25 dB HL or less. The hearing loss group had mean hearing thresholds ranging from 20.0 to 56.3 dB HL at 250-6000 Hz and had PTAs in the better ear of greater than 25 dB HL. Study participants were asked to listen to 16 strings of words which ranged up to 15 words in length. The strings of words varied in the four degrees of order based on contextual limit (i.e., the number of words prior to a target word that might help an individual have better perception of the word). The degrees of order used were: zero and first orders of approximation; second and third orders of approximation; fourth and fifth orders of approximation; and seventh and ninth orders of approximation with four lists of English words presented for each order pair. For example, zero order would represent a target word with no preceding words offering prior context, (e.g., “better write catch native evening bit position wish small proper grass”), whereas an example of third order would be a target word preceded by nine words of prior context (e.g., “family was large dark animal came roaring down the middle of my friend’s love books”) (p.25). Participants listened to each string monaurally in the better ear (re: PTA) at a presentation level of 75 dB HL. The degree of order presentation was randomized and the task was for the participant to listen to each word string with random stops during the strings. Participants were instructed to verbally respond by recalling the last three words in the string prior to the stop (e.g., “better write catch native evening bit position wish small proper grass”) should result in a report of “small proper grass” (p. 27). Results indicated that accuracy for recalling the final word in each word string was 99.5% for the better hearing group and 98.2% for the hearing loss group, regardless of the order of approximation. These investigators suggested that this offers evidence that hearing loss did not impact the audibility of words within the three-word set. However, results showed that there was a significant effect on recall of the three word sets and order of approximation as well as a significant hearing group effect. Specifically, results were indicative of differences in recall performance between the two groups for the lower orders of approximation (i.e., those with little or no context). The hearing loss group demonstrated significantly poorer recall for word strings with low contexts/constraints compared to performance of the group with better hearing. In examining the significant group effect, the investigators found poorer recall for the first two words in the three-word set by the hearing loss group. This led the researchers to suggest that those with hearing loss exerted more perceptual effort to recall the words and that this additional effort ultimately affected memory performance in low context situations. Therefore, these results indicate that hearing losses of mild-to-moderate degree affected memory recall. McCoy et al. concluded that the reason the two prior words were missed in the hearing loss group was not due to an inability to recognize the words, but rather to an increase in amount of processing effort needed for accurate identification of speech. This directly impacted downstream processing and cognition. As cognitive resources were being expended for the purpose of immediate recall, the process of encoding the information into memory via rehearsal did not occur, compromising the ability to utilize working memory.

Attention.

Attention has numerous definitions according to Webster's dictionary; however, the primary definition stated is: "the act of keeping one's mind on something or the ability to do this" (Webster's New World College Dictionary, 2007, p. 91). Animal and human research studies relative to attention have been conducted in different (albeit related) fields of study such as psychology, psychoacoustics, neurobiology, neuroscience, neurophysiology, otolaryngology, gerontology, genetics, and audiology. This research has incorporated different methodologies including behavioral, electrophysiological, and brain imaging measurements, which make interpretation across bodies of research challenging (Fritz, Elhilali, David, & Shamma, 2007). Despite the lack of consensus on the most appropriate definition for attention, researchers are in agreement that the brain cannot limitlessly attend to all sensory inputs at one time. Classic investigations of visual and auditory attention have led to development of sensory models of attention. As these models attempt to emulate the sensory function of the brain, it is important to discuss research relevant to anatomical location for auditory attention, as well as attention factors such as selective and divided attention, and inhibition and saliency maps which are specific mechanisms within the sensory system.

Historically, the study of attention stems from cognitive psychology and was first established in the 1950's relative to phenomena in hearing by such researchers as Cherry (1953) and Broadbent (1958) who described "the cocktail party phenomenon" and the "filter model", respectively (Driver, 2001; Groome, 2006, p. 67-68). The work of Cherry (1953) solidified the concept of attending to specific speech stimuli such as one voice, while un-attending to a barrage of voices in the background. The work of Broadbent (1958) established the concept of processing or "extracting" the physical properties of one signal (attended input, i.e., one voice) while filtering out another signal (un-attended input, i.e., background noise) (Driver, 2001, p. 54-56; Groome, 2006). Broadbent's (1958) filter theory is an important concept as it supports functional significance of short term memory such that cognitively one does not become overloaded with processing attended and un-attended information (Groome, 2006). The key mechanism of the filter theory was a two-stage filter process which allowed for parallel and serial processing to occur. That is, at the first processing stage the physical attributes of the stimuli could be relayed via several "parallel" channels, while in the second "limited-capacity" processing stage, the abstract stimuli could be processed via a single "serial" channel (Driver, 2001, p. 56; Mildner, 2008). Although there were inherent problems to Broadbent's (1958) filter model, it laid the foundation for the development of other models of attention relative to both vision and hearing.

One of the main arguments regarding Broadbent's (1958) filter theory revolves around early versus late attention processing. The filter theory purports the idea that early processing of physical attributes relative to attention information occurs during the first stage (i.e., early). However, because of the selective filter, the only properties of the un-attended message that pass through the filter are those physical attributes that closely relate to the original message. Thus, the theory did not address the potential processing of un-attended abstract information into semantically relevant information in a later stage. Therefore, many researchers set out to disprove Broadbent's theory by arguing that the un-attended message was not lost, but rather processed at a later or attenuated stage (Driver, 2001; Groome, 2006).

One such proposed theory came about in the 1960's by Broadbent's doctoral student, Anne Treisman, who introduced the attenuation model (Driver, 2001; Groome, 2006). This model proposed that the un-attended message was not lost, but processed at a deeper stage, albeit as a weaker input, than the processing that occurred for the attended message. An analogy offered by Groome (2006) relative to the attenuation model was that of a radio dial being turned down. That is, the message could still be processed; however, as a much weaker signal. The attenuation model goes beyond Broadbent's (1958) theory, including processing on three distinct levels. During the first processing level, the physical attributes of the stimuli are processed such as speaker gender and/or location in a room. At the second level of attenuation processing, properties of the stimuli are determined such as whether information is speech based. Once the stimuli has been analyzed at this second level, if it is speech related then further processing or grouping of the stimuli into syllables and words occurs (Groome, 2006). The third level of processing is considered the highest level as it deals with identifying the meaning of the stimuli (Groome, 2006). This third level is referred to as the "semantic-level" due to the processing of the linguistic component into something meaningful (p. 71). In addition to the three levels of processing, the attenuation model is viewed as a model that allows for greater flexibility in the processing of the un-attended message which equates to ability to switch attention for highly sensitive material such as when hearing one's own name (Groome, 2006). The attenuation model is widely accepted as a major auditory attention model as it includes aspects of Cherry's

(1953) research on the cocktail-party effect as well as aspects of Broadbent's (1958) filter theory and further separates auditory stimuli into processing levels that are "cognitively economical" (Groome, 2006, p. 72).

Functionally, attention involves cognitive processing of task-relevant information (Alain & Woods, 1999; McDowd, 2007). Attention requires one to focus on a desired task while subsequently ignoring non-relevant information within the environment. McDowd (2007) also indicates that individuals control resources for the "allocation of attention" such as "attentional effort", as well as "internal and external control of attention" to successfully process attention related information (p. 98-99). These elements provide a means for 1) allocating attention toward a preferential task (or multiple tasks) as long as this allocation does not deplete available cognitive processing resources, and 2) expending additional effort on a specific task especially when challenged by external factors. Depending on the intended goal of the listener, successful processing of attention relies on both internal and external attention controls. Internal control is simply the individual maintaining focus on the task at hand, while external control is the act of introducing other stimulation to divert or attract a listeners' attention from or toward the relevant task information. External distracters occur in every environment and can affect efficiency with which information is processed. Thus, in order to demonstrate efficient attention behavior, one needs a balance between internal and external attention control (McDowd, 2007). In addition, relative to attention effort, Sarter (2006) as discussed by McDowd, suggests this to be an "active", "top-down" controlled function that is directly related to an individual's motivation pertaining to the task at hand (p. 99). The anatomical location for the processing of attention effort is said to be within the "cortical, mesolimbic and cholinergic systems" (McDowd, 2007, p. 99).

Attention processing can be further specified into four general categories depending on the task to be accomplished. One attention component is selective attention (McDowd, 2007) which refers to focused attention such that the individual is directed to respond to only one source of information, regardless of the presence of potential distracters. Relative to experimental data obtained in selective attention tasks, McDowd indicates that variables such as similarity of target versus distracter, target location predictability, distracter interval predictability, and separation of target versus distracter are all critical considerations. Another component of attention is divided attention (McDowd, 2007). Divided attention is processing (or responding to) multiple sources of information at a given time. As long as the tasks being performed do not infringe on cognitive resources available, there is no impact on performance of either task. However, if the tasks are too difficult, then the result is a decline in performance on one or both tasks (McDowd, 2007).

The third category of attention is attention switching (McDowd, 2007). As implied, attention switching refers to re-focusing one's attention on a secondary source relative to multiple attention sources. Attention switching differs from divided attention in that although there may be multiple sources of information to process, the focus is only on one source at a time with quick attention changes between sources. While switching attention may be an appealing mechanism for supplementing divided attention tasks, McDowd (2007) warns that attention switching is cognitively more demanding and can lead to slower and/or poorer task performance. In other words, attention switching tasks (also referred to as alternating attention), introduce a greater cognitive load than divided attention tasks.

The ability to sustain attention is another factor related to the processing of attention. Sustained attention is also known as vigilance and refers to staying focused on a task over a period of time (McDowd, 2007). Vigilance requires effort and good attention control on behalf of the individual. The inability to sustain attention is known as vigilance decrement and may be the result of individual (e.g., fatigue and stress) and methodological (e.g., frequency of and predictability of target) factors (McDowd, 2007).

All four aspects of attention (selective, divided, switching, and sustained) are critical to consider as people use various attention abilities on a daily basis, such as focusing on a conversation while in a noisy restaurant. Furthermore, empirical evidence shows that performance on tasks requiring attention are affected by aging (Alain & Woods, 1999; Harris, Dubno, Keren, Ahlstrom, & Eckert, 2009; McDowd, 2007; Robin & Rizzo, 1992; Rowe, Valderrama, Hasher, & Lenartowicz, 2006). This is observed even when hearing loss has been accounted for and found not to be a factor influencing results (Humes, Lee, & Coughlin, 2006).

Although attention is processed through both the visual and auditory systems, the overwhelming majority of literature addresses attention processing via the visual system. However, there are several terms such as; *iconic*, *echoic endogenous*, *exogenous*, *saliency*, and *inhibition* that apply to one or both modalities. Iconic (memory) refers to information visually processed while echoic (memory) refers to the processing of auditory information. According to Mildner (2008), iconic memory span is approximately half a second while echoic memory span is approximately 300 to 500 ms long. However, if the sensory information is worth remembering, information can be retained for longer periods of time via practice and/or rehearsal which ultimately allows the information to be transferred into short term or working memory (Mildner, 2008). The term *endogenous* refers to consciously or voluntarily directing one's attention to stimuli, while the term *exogenous* refers to the unconscious or automatic processing of stimuli (Alais, Morrone, & Burr, 2006; Wrigley & Brown, 2004). As the human brain is incapable of processing all stimuli concurrently, the endogenous and exogenous systems are neural mechanisms within the brain that act as sensory attention processors, assist in processing relevant information (Kayser, Petkov, Lipert, & Logothetis, 2005). Saliency is a theoretical construct relating to the processing of features of the sensory stimuli that recruit one's attention more easily than other stimuli in the proximity (Kayser et al., 2005). In other words, salient properties are more detectable within a visual or auditory scene and thus attract one's attention toward the respective stimuli. This saliency processing is very quick (25- 50 ms visually) (Itti & Koch, 2001), and occurs through both bottom-up and top-down components (Itti & Koch, 2001; Kayser et al., 2005).

One aspect that can contribute to deficits in attention processing is that of inhibition. *Inhibition* is a term used to describe the suppression of irrelevant information to allow for the regulation of attentional processing of relevant material (Rowe et al., 2006). This is an important aspect of attention to consider as deficits in inhibitory manipulation may be another factor contributing to attention and cognition problems in the elderly population (Alain &Woods, 1999). In addition, as Rowe et al. (2006) point out, the regulation of inhibition may be altered relative to the time of day an individual performs a task as well as a result of aging. In their study, Rowe et al. examined the effects of inhibition ("attentional disregulation") on memory (implicit) based on the time of day the task was performed (p. 826). Using young adults ranging in age from 18-30 and older adults ranging in age from 60-75, each participant was determined to be either a morning person or an evening person. Scores from the "*Horne-Ostberg Morningess-Eveningness Questionnaire (MEQ"* (p. 827) classified older adults as preferring the morning hours, while young adults were classified as preferring the afternoon or evening hours. Regardless of the individual's preference, all participants were tested during their preferred time of day (peak) and during a non-preferred time of day (off-peak). Testing consisted of a study phase and a test phase with a visuospatial working memory filler task (*Corsi Block Test*) in between the phases. In the study phase, participants watched a computer screen that flashed 55 pictures paired with either a superimposed letter string or word. The task required the participant to ignore the letter string or words and press the computer keyboard space bar to indicate when they saw two identical pictures back-to-back. During the test phase, participants watched a computer screen in which 30 word fragments (from distracter words in the study phase) were displayed. The participant verbally responded with the first thing they thought of once they saw the word-fragment. The purpose of the test phase was exploring a priming effect relative to the word-fragments to determine if the distracter word was ignored during the study phase. Results indicated an interaction between the time of day testing occurred and age; the older adults had greater memory for distracter words during afternoon hours, whereas younger adults had greater memory for distracter words during morning hours. The older adults had significantly better memory for distracter words indicating an inability to effectively ignore the distracter words.

In contrast, other researchers have found similar inhibition in young and older listeners when certain variables are controlled (Murphy, McDowd, & Wilcox, 1999; Robin & Rizzo, 1992). Specifically, Murphy et al. (1999) found that after controlling for decreases in hearing sensitivity by: 1) ensuring that older participants had symmetrical hearing loss; 2) editing speech stimuli in a manner that would minimize background noise; and 3) utilizing edited stimuli such that the presentation level of the material was sufficient relative to the participants hearing loss, younger and older adults demonstrated similar inhibition.

Robin and Rizzo (1992) measured younger and older adults' ability to orient attention in the visual mode, the auditory mode, and a mixed-mode (i.e., random presentations of visual and auditory orienting trials). During visual attention trials, participants saw an arrow on a computer screen and were to press a touch switch indicating the appropriate direction. During auditory attention trials, participants heard a tone in either the right or left ear and were asked to report the ear. Participants were advised that they were to respond as quickly as possible and that they were being timed. Robin and Rizzo reported that although reaction times were slower in the older participants, both younger and older adults were able to selectively attend to the stimuli. Furthermore, these investigators found that reaction times for both groups were shortest for auditory conditions and longest for mixed-modality conditions. These results are supportive of the need for greater attention resources when there is unpredictability with respect to the information modality.

When a task requires greater attention resources, then inhibition is more difficult because cognitive resources are limited. Limited inhibition can impact both visual and auditory systems (Alain & Woods, 1999; Murphy et al., 1999; Robin & Rizzo, 1992). Collectively, these studies do not indicate that inhibition is due to the aging process of each system alone, but rather occurs as a result of cognitive, perceptual, and sensory deficits. As a result, some researchers have proposed that inhibitory mechanisms concurrently modulate attention control, while other researchers have proposed that attention control is maintained within each sensory system. Robin and Rizzo (1992) concluded that the mechanisms for inhibition appear to be the same as both their younger and older participants had similar orienting abilities for attention, regardless of modality. However, Murphy et al. (1999) indicated that the possibility exists for different deficits for inhibition relative to the sensory modality (i.e., perceptual inhibition related to deficits in the central auditory processing system or peripheral inhibition as a result of hearing impairment). This perspective lends support for two separate mechanisms for inhibitory or selective attention control within the visual and auditory systems.

Recently, Alias, Morrone, and Burr (2006) conducted a mixed-modality experiment in which participants attended to discrimination of pitch (auditory) and contrast (visual) stimuli. Discrimination of pitch and contrast thresholds were measured separately. Each discrimination task was repeated with a distracter task of the same or opposite modality. The visual contrast task was unaffected by the auditory distracter task and the auditory discrimination task was unaffected by the visual distracter task. Distracter tasks of the same modality significantly raised discrimination thresholds for auditory and visual discrimination tasks. As with the conclusion offered by Murphy et al. (1999), the results of Alias et al. (2006) support independent resources for visual and auditory attention control.

Attention and audition.

Humes et al. (2006) designed two experiments to assess the effects of aging on auditory selective and divided attention, to determine if the strength of auditory cues contributes to selective and divided attention abilities and to measure the effect of talker uncertainty on attention (Humes et al., 2006). For both experiments, participants were divided into two groups comprised of ten normal hearing young adults and 13 hearing impaired elderly adults. The age ranges were 21-34 and 61-81 for the young and elderly groups, respectively. Hearing thresholds were screened at 20 dB HL for the younger participants from 250-8000 Hz, with each participant passing the screening. Older adult participants all had sensorineural hearing loss that varied in degree of severity with mean thresholds for the group ranging from 20-55 dB HL from 250-8000 Hz, binaurally. Each of the 23 participants passed with a score of at least 27 out of 30 on the *Mini Mental State Exam* (*MMSE*) (Folstein, Folstein, & McHugh, 1975) and had passing forward and backward digit span scores (i.e., recalled a sequence of at least 5 digits for forward digit span, and had a backward digit span of at least 4 digits), in order to rule out cognitive and memory impairments. Stimuli used in the first experiment were presented using the *Coordinate Response Measure (CRM)* procedure (Bolia, Nelson, Ericson, & Simpson, 2000). The CRM is a closed-set test that uses synthetic sentences spoken by four male and four female talkers in which participants are visually cued as to which speaker's upcoming sentence stimuli they should attend. Two sentences containing similar context are paired and simultaneously presented either to the same ear (monaural condition) or to opposite ears (dichotic condition). Prior to each sentence pair, participants were visually provided with an ear notification (right/left), speaker (male/female), or call sign (lexical information related to the target) designation for the target sentence. The listener's task was to focus on the target sentence and identify the color and number words in that sentence while ignoring the competing sentence. All target sentences were of the format "ready, go to color, number now" with participants asked to press response buttons corresponding to four colors and eight numbers (p. 2928). For the selective attention task, cues were provided prior to sentence pair presentation, while during the divided attention task, cues were not provided until after the sentence pair presentation. The first experiment consisted of examining six conditions of selective attention and six conditions of divided attention. To compensate for the varying degrees of sensorineural hearing loss among the elderly group, the CRM material was spectrally shaped to allow for sufficient audibility for frequencies up to 6000 Hz for these listeners. Presentation levels were selected in order to allow for at least a 15 dB sensation level for all listeners. Control conditions for each ear for the elderly group were run (without competing speech) to verify that sentence materials could be accurately identified. Results from the control run indicated that the elderly group did not demonstrate any problems identifying the spectrally shaped target sentences. Results from the first experiment relative to the dichotic condition for selective and divided attention revealed significant main effects for type of cue (i.e., ear cue vs. call sign) and gender of the speaker. The elderly group performed more poorly than the younger group in all selective and divided attention conditions. Pairwise correlation measures for performance on monaural vs. dichotic tasks were conducted and revealed that there were strong, positive and significant correlations between auditory selective and divided attention task performance.

In experiment two, Humes et al. (2006) established six conditions (three for selective attention and three for divided attention) to examine cued stimuli for speaker gender. Twenty three participants were used in this experiment to include ten young normal-hearing adults and 13 elderly hearing impaired adults. The stimuli consisted of "levels of talker uncertainty" described as: 1) minimum uncertainty in which the same female and male talker was used across trials; 2) medium uncertainty had two conditions: one trial used a fixed female talker with variable male talkers and another trial used a fixed male talker with variable female talkers across trials; and 3) maximum uncertainty in which one of four female and one of four male talkers were randomly chosen as the possible talker. As the analysis focused only on talker uncertainty, presentation mode was monaural (right ear) and the cue was only for gender of the speaker. Results revealed that, in general, the elderly participants had poorer performance in the divided attention task than the younger participants. For all three uncertainty levels, the divided attention scores for older adults were lower than the selective attention scores. The elderly participants performed poorer than the younger participants for the medium and maximum talker uncertainty conditions. The investigators concluded that although the uncertainty data is less clear, experiment two data supports experiment one data due to the fact that the elderly group performed more poorly in the majority of conditions (five out of six). Correlation analysis for the three talker uncertainty conditions revealed a statistically significant, positive, strong correlation between performance on selective and divided attention tasks for all 23 participants. Further correlation analysis for the elderly participants between the six conditions and age, hearing loss, and digit span performance revealed a negative correlation between age and performance for maximum uncertainty in the divided attention task, as well as a significant moderate correlation for digit span and all three uncertainty conditions in the selective attention task. Relative to the overall findings from these two experiments, the researchers drew several conclusions. First, divided attention performance for both groups was poorer than selective attention. Second, group differences were evident in that the elderly group performed poorer than the younger group in eight out of nine conditions. Third, despite individual performance differences, selective and divided attention performance was strongly correlated with the Coordinate Response Measure (CRM) scores. According to Humes et al. (2006), these results support the possibility of a common underlying mechanism for cognitive processing on these tasks. However, the fact that there was no significant correlation between age and hearing loss but a moderate correlation between age and performance for digit span may be indicative of age-related memory deficits as a contributing factor to decreases in performance on attention tasks in older adults. It should be noted that the tasks of Humes et al. (2006) might be better considered as assessments of selected and divided recall in that tests of attention only do not require recall of items.

Processing speed.

The concept of how quickly information is processed throughout the auditory system is another concern relative to hearing and the aging auditory system. *Processing speed* is not defined by a single definition but is associated with various measures. Salthouse (2000) indicated that different types of processing speed assessments are found in psychometric, psychophysical, and physiological research. From the psychometric realm, speed variables such as *decision speed* and *perceptual speed* are addressed. Decision speed reflects the time it takes to respond on cognitive tests set at a moderate level of complexity whereas perceptual speed reflects an individual's response speed on simple tasks. Experimental and psychometric researchers use *psychomotor speed* measures, most notably *reaction time*, to assess speed variables of an individual. Psychomotor speed or reaction time also uses simple tasks to measure speed of a motoric response whereas *psychophysical speed* is measured using quickly presented visual or auditory stimuli in which the individual makes an accuracy decision relative to the presented stimuli. In physiological research, the timing of neural responses can be measured by examining the latency of event-related potentials. All of these measures can be used for tasks involving different stimulus modalities (i.e., auditory, visual, verbal, or motor). Performance on tasks can be affected by speed of response, accuracy, and cognitive ability.

With respect to the effects of aging, generalized slowing in brain performance related to auditory and temporal processing (Pichora-Fuller, 2003), cognition (Jerger, 2009; Wingfield, 1996), language (Gordon-Salant et al., 2006; Gordon-Salant & Fitzgibbons, 2001; Schneider et al., 2005), memory (Jerger, 2009, Schneider et al., 2005), motor processing (Wingfield, 1996), neurobiology (Finkel et al., 2007; Rabbitt et al., 2006), and perceptual processing (Pichora-Fuller, 2003) has been observed. Processing speed deficits among the elderly have been extensively researched going back as far as the 1920's (Salthouse, 1996). Within this body of research comes processing speed perspectives predominately from psychology (Finkel, Reynolds, McArdle, & Pedersen, 2007; Salthouse, 1996, 1998, 2000; Stewart & Wingfield, 2009; Wingfield, 1996) with contributions from audiology, gerontology, and radiology (Gordon-Salant, Fitzgibbons, 2001; Gordon-Salant, Yeni-Komshian, Fitzgibbons, & Barrett, 2006; Jerger, 2009; Pichora-Fuller, 2003; Rabbitt, Scott, Thacker, et al., 2006; Schneider, Daneman, & Murphy, 2005; Zimprich, Hofer, & Aartsen, 2004). Evidence from these researchers indicates that there are several factors contributing to overall processing speed deficits demonstrated in the elderly population. These factors, such as age-related changes relative to: sensory deficits (Schneider et al., 2005), auditory temporal processing/perceptual abilities (Gordon-Salant & Fitzgibbons, 2001; Pichora-Fuller, 2003), cognitive slowing (Pichora-Fuller, 2003; Wingfield, 1996), memory deficits (Finkel et al., 2007; Pichora-Fuller, 2003, Salthouse, 1998; Stewart & Wingfield, 2009; Wingfield 1996) and changes in brain volume and cerebral blood flow due to aging (Rabbitt et al., 2006), are not mutually exclusive and can affect information processing in isolation as well as congruently.

One of the most prominent researchers on the subject of processing speed, Salthouse, has provided a plethora of analytical and empirical evidence in support of aging effects on processing speed. In 1996, Salthouse offered a theory relative to processing speed and cognitive aging. According to Salthouse's theory, memory and cognition are compromised due to a decrease in processing speed as a result of aging. The older one gets, the slower the processing speed. This slowing can lead to difficulty with memory and cognitive functions. To support this notion, Salthouse (1996) reported on multiple statistical analyses performed by Salthouse (1985, 1992), Kail and Salthouse (1994), Schaie (1989), as well as Schaie and Willis (1993). Salthouse (1996) noted that correlations of .45 have been found between measures of processing speed and subject age. Furthermore, when performing perceptual speed measures, "pronounced age trends" have been evident on a wide variety of paper-based, and computerized test batteries including the; *"Digit Symbol Substitution Test"*(Wechsler, 1981), *"Visual Matching and Cross-Out Test"* (Woodcock Johnson Test of Cognitive Abilities-Revised; Woodcock & Johnson, 1989) and *"Finding A's and Identical Pictures"* (Ekstrom, French, Harman, & Dermen, 1976) tests to name a few (p. 406). Collectively, results from these tests in several studies reviewed and reported by Salthouse (1996), revealed a "moderate-to-large" correlation between processing speed and age. Results from studies using behavioral tests in individuals ranging from 19 to 83 have indicated that age is a factor in processing speed deficits with the general trend being a linear decrease in processing speed with increasing age (Salthouse, 1996). Salthouse also observed a lack of a single contributing age-related processing factor, but rather that there are several common factors which include "knowledge, reasoning, memory, perceptual speed, closure and quantitative processing" (Salthouse, 1998, p. 853) and reaction time (Salthouse, 2000). Control analysis, conducted to determine amount of variance from a particular factor, indicated that close to 75% of the age-related variance observed on cognitive tests such as: free recall, working memory, verbal and spatial memory matrix tasks are shared with processing speed assessments.

In addition to aging and related changes in processing speed, Salthouse (1996) described two contributing factors, the *limited time mechanism* and a *simultaneity mechanism*. These mechanisms contribute to overall processing speed deficits demonstrated in the elderly population for simple and complex cognitive operations as well as when performing multiple tasks at the same time. The limited time mechanism refers to a reduction in the ability to process or perform "later" functions as a result of the amount of time expended on processing or performing "early" functions. Simply stated, the more there is to process, the longer it takes to process, which results in "less processing of information" in the allotted time (p. 422).

Analytical and empirical evidence presented by Salthouse (1996) supports the limited time mechanism hypothesis. Salthouse (1996) reported results from an unpublished study conducted by Kersten and Salthouse (1993) in which 78 participants (39 young adults with a mean age of 20; and 39 older adults with a mean age of 67) were asked to perform an associative memory task. The purpose of the task was to assess performance on cognitive tasks relative to the amount of time allotted for information processing. The task involved the presentation of a continuous string of letter-digit pairs and the individual had to determine (at different time spans) if a designated letter-digit pair had been presented together. There were two decision time measures on the task. The first time measure occurred immediately following the initial digit-pair presentation and was referred to as lag 0, while the second time measure, lag 1 occurred following one additional digit-pair stimulus presentation. Therefore, cognitive measurements for accurately processing the digit-pairs were obtained for immediate and time delayed processing. Results indicated that the elderly group 1) performed less accurately (i.e., 53% - 83% for lag 0 and 52% - 70% for lag 1) compared to the younger group (i.e., 65% - 92% for lag 0 and 58% - 88 % for lag 1), 2) had poorer time-accuracy function (i.e., lower percentage correct and longer time needed for accuracy), and 3) required more decision time for processing lag 1 pairs, than for lag 0 pairs. These findings supported the limited time mechanism in that when compared with the younger group, the elderly group demonstrated less processing relative to the amount of time available to perform this particular task.

The simultaneity mechanism closely resembles the concept of working memory as proposed by Baddeley (1986) and is similar to other cognitive processing views such as Eyesenck (1987), Jensen (1982; 1987), Vernon (1983; 1987), Biren (1965; 1974), Jones (1956), Lemmon (1927), and Travis and Hunter (1928), as reported by Salthouse

(1996). Functions such as retrieval and rehearsal are negatively impacted by slower processing time. Therefore, the slower processing causes deteriorations in the quantity and/or quality of task relevant information (Salthouse, 1996). The two mechanisms together (limited time and simultaneity) may yield an increase in processing errors and/or increase in the time it takes for performing "critical operations" (p. 406). When processing speed is slowed due to extra time needed to perform these operations, then information may be lost based on the approximate short-term memory storage time of two seconds. The simultaneity mechanism operates under the constraint of the limited time mechanism in that, if processing is slow, then pertinent information may dissipate or be completely lost when needed for later assimilation (Salthouse, 1996). Salthouse postulated that the principle age-related factor of the simultaneity mechanism was due to slower processing speed and not due to the rapid decrement of information. Other relevant points made by Salthouse (1996) relative to this mechanism were that: 1) information processing may be further compromised if there are neural synchrony disruptions, 2) multiple processing systems are involved, thus if relevant information is being lost due to slow processing, then high-order processing can be affected, 3) slower processing and loss of information prior to processing in higher-order systems can impact overall performance in the form of increased errors, and 4) cognitive performance may be directly impacted by speed effects such that the effectiveness of cognitive processes (i.e., abstraction, elaboration and integration) are altered. These are important considerations as they represent several internal inefficiencies of cognitive processing rather than being solely due to time constraints. In fact, based on computational model analysis conducted by Salthouse during the late 1980s, slower processing speed does not cause a singular "catastrophic loss" for processing; however, it can lead to a "diffuse reduction in the efficiency of processing" for multiple processes (p. 406). In support of this, Salthouse (1998) presented results from statistical analyses of cognitive abilities for individuals' ranging in age from five-years-old to 94-years old. Based on these analyses, Salthouse reported that declines in processing speed are correlated with numerous cognitive abilities (i.e., reasoning, knowledge, short-term memory, perceptual speed, associative memory, and closure), regardless of age. These results further support the general conclusion that performance on these tasks are influenced by aging as well as other shared cognitive factors such as perceptual processing and reaction time. Furthermore, these analyses also indicated that much of the age-related shared variance depended on higher-order cognitive function. Although age and cognitive abilities influence processing speed there were not distinct independent differences across the life span in which a single developmental or cognitive factor could explain the decline in processing performance. Thus, several variables can be attributed to decreased processing speed in older adults.

Salthouse (2000) reviewed a series of studies by various researchers exploring aging as an influential factor on processing speed performance. He observed that: 1) the strongest correspondence to age-related difficulty was attributed to speed variables relative to biological and behavioral measures, 2) the health condition of an individual, based on self-reports, does not play a role in processing speed performance, 3) practice on material relative to speed tasks (i.e., reaction time, memory, and visual tasks) is not affected by age, and 4) type of task (such as spatial, verbal, lexical or arithmetic) relative to speed of processing and age does not impact performance. Salthouse indicated that the overwhelming majority of research evidence based on reaction time measurements points to an overall performance decrement for older participants compared to younger participants. In addition, he stated that multiple analyses reveal that a moderate to large correlation between aging, processing speed, and cognition does exist.

Researchers have investigated the way in which increased speech rate affects elderly adults' ability to process speech. These investigators have suggested that difficulty with perceiving speech at fast rates also indicates a processing speed or temporal processing deficit. On average, the normal conversational speech rate ranges from "140-180 words per minute, while the average broadcaster's rate of speech can exceed 210 words per minute" (Wingfield, 1996, p. 175). If a given speech rate exceeds an individual's temporal processing speed, then speech perception may be negatively impacted. Furthermore, declines in processing speed are not directly related to hearing sensitivity, but rather are related to a compilation of alterations throughout the auditory system and brain. Difficulties with perceiving fast speech rates have been observed in the elderly population even when younger and older participants are matched relative to hearing sensitivity (Wingfield, 1996). Temporal processing deficits in older adults with and without hearing loss can affect perceptual, cognitive, and linguistic abilities. Studies related to age-related temporal changes also provide evidence that these changes lead to deleterious perceptual effects as they may be related to neural degeneration and cognitive and language processing declines (Pichora-Fuller, 2003).

One way to measure temporal processing difficulty is by conducting experiments with the use of time-compressed speech (Gordon-Salant & Fitzgibbons, 2001; Wingfield, 1996), or speeded- speech (Schneider et al., 2005) in which recorded speech (word strings or sentences) are altered in both rate and duration such that the end result is accelerated speech segments that do not alter the frequency characteristics. One of the leading researchers in this area is

Wingfield. Throughout his 30 year career, Wingfield has offered foundational research regarding cognitive declines and language. Wingfield (1996) acknowledged the breadth of cognitive and linguistic interactions that ultimately contribute to age-related declines in processing speech. He conducted a series of studies using young normal hearing participants ranging in age from 18-22 and older participants with age-appropriate hearing ranging in age from 63-76. These studies examined the cognitive processing of contextual information for both analytic and synthetic speech materials in speeded conditions. Wingfield created three different types of speech materials, i.e., meaningful sentences, syntactically structured word sequences and random word strings that were unstructured with no meaning. These materials were presented to study participants at four different speech rates of 275, 325, 375 and 425 words per minute. The participants listened to and repeated the sentences or word strings. A percent correct score was then obtained for each type of material at the various speech rates. Because identification of unstructured word strings is a cognitively challenging task representing one's pure processing ability, improved scores for sentences with contextual information supports the use of linguistic knowledge. Both the younger and older groups performed at ceiling levels on the meaningful sentences. However, scores were markedly different for the random word strings between groups. On those materials, the elderly participants had scores ranging from 65% at a speech rate of 275 wpm down to 38% at 425 wpm, while the younger participants had scores ranging from 83% at 275 wpm to 79% at 425 wpm. Wingfield indicated that all participants demonstrated the ability to utilize linguistic knowledge as evidenced by significantly higher scores on the meaningful sentences. Results revealed that although elderly individuals with near-normal hearing demonstrated poorer performance in identifying time-compressed speech, these individuals were able to compensate for this processing deficit through an ability to maintain linguistic knowledge of speech content.

Wingfield (1996) observed that “word-onset gating” experiments show that older and younger listeners are able to use contextual information to enhance word identification (p. 178). Word onset gating refers to the presentation of a single word in such a way that the acoustic segment from word onset is increased in small increments until an individual can recognize the word. The identification of words in isolation occurs at about 330 ms from word onset whereas word identification within sentence material occurs at approximately 200 ms from the onset of words presented within a sentence. Wingfield stated that elderly individuals with age-appropriate hearing require, on average, 50 ms longer (i.e., 380 ms) compared to younger normal hearing adults in order to recognize a word in isolation during such word gating conditions. Although there were age-related differences between younger and older adults for gating of words in isolation, there were no such age-related differences for words presented in sentence context.

Wingfield (1996) evaluated the memory capability for linguistic context of younger and older adults with age appropriate hearing. Participants were asked to accurately identify one to four words preceding a target word as well as identify one to four words following a target word. Wingfield reported a significant context effect for the younger and elderly participants’ abilities to identify words. Both the younger and older adults performed similarly for identification of one, two, three, and four words preceding the target word. However, analysis of performance between the groups for words following the target word indicated a significant context effect and age-context interaction. This interaction was reflected in poorer word identification scores for the words following the target word (i.e., approximately 25%-50%) by older participants compared to scores for younger participants (i.e., approximately 38%-70%). These apparent memory constraints may hinder an older individual's ability to utilize contextual information for the perception of speech, especially when in challenging listening situations. These findings indicate that both younger and older individuals utilize both top-down processing of semantic and syntactic information and bottom-up phonological processing in order to process speech. These results suggest that as one ages, and deficits in processing information in a bottom-up manner occur, then top-down processing abilities may be relied upon more heavily in order to counterbalance the system.

Support for Wingfield's (1996) findings and reported observations have been offered by research conducted by Gordon-Salant and Fizgibbons (2001). These researchers recruited participants ranging in age from 19-75 to assess the effects of aging and hearing loss on the identification of time-compressed speech, and how that performance related to processing speed and processing of acoustic cues. Participants were dividing into the following four groups: a) young normal hearing listeners, b) older normal hearing listeners, c) young hearing impaired listeners with gradually sloping mild-to-moderate sensorineural hearing loss from 250-4000 Hz, and d) older hearing impaired listeners with gradually sloping mild-to-moderate sensorineural hearing loss from 250-4000 Hz. Material for the study was derived from the *Revised-Speech Perception in Noise Test (R-SPIN)* (Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984) which includes low context and high context sentences. The R-SPIN sentence materials were used to develop three sets of stimuli: sentences (SEN), syntactic sets (SS), and random-order words (ROW). The SEN stimuli consisted of original R-SPIN sentences that offered little semantic information (i.e., low context sentences), the SS stimuli involved use of only low-probability content from the noun, verb, and object of the sentences, and the SS stimuli incorporated the noun, verb, and object phrases with a randomly ordered presentation of the words. In addition, there were four time-compression conditions for these materials. The first time-compressed condition, uniform-time compression (UNI TC), consisted of the entire sentence-length material being compressed by 50%. The second condition, selective time compression of pauses (STC-P), compressed pauses by 50%. The third condition, selective time compression of vowels (STC-V), compressed vocalic segments by 50%. The last condition, selective time compression of consonants (STC-C), compressed consonants by 50%. The speech stimuli were presented monaurally to all participants at 90 dB SPL re: the ear with the better threshold (hearing loss groups) or to the right ear (normal hearing groups). The task of each participant was to write down all words that they heard, even if they had to make a guess. Results from this study revealed that regardless of stimulus condition, hearing impaired participants demonstrated significantly poorer identification than normal hearing participants. In addition, all participants had a significant decrease in performance with reduced linguistic information. However, both the older normal hearing and older hearing impaired group had significantly poorer performance scores relative to the younger participants, especially in the condition with the least linguistic information (i.e., random-word order condition). Furthermore, analysis conducted on the time-compressed conditions indicated: 1) a significant effect for the random-word-order condition, 2) a significant age effect for the uniform-time compression sentence and selective time compression of consonants for the synthetic set conditions, and 3) a significant age by hearing loss interaction for uniform-time compression, for selective time compression of consonants (STC-C) and for selective time compression of vowels (STC-V). Interestingly, no performance decrement for selective time compression of pauses was observed for all listeners for the random-word order condition relative to the significant performance decreases in performance for uniform-time compression, selective time compression of consonants, and selective time compression of vowels. In addition, older adults showed only a minimal performance decrease for the selective time compression of vowels for the sentences, synthetic sets, and random-word order conditions. However, the older adults and younger and older participants with hearing loss all demonstrated significant performance decrements for selective time compression of consonants in the synthetic set and random-word order conditions. Thus, these investigators concluded that age-related difficulties in perceptual processing of time-compressed speech (by older individuals) reflects limits of the aging system for the processing of brief acoustic cues in consonant sounds. Also, the fact that these older listeners and the individuals with hearing loss had significant differences in performance relative to younger and normal hearing individuals indicates that these individuals are more negatively impacted by speeded speech, especially for 50% compression and for consonant identification. Taken together these results provide further evidence that both bottom-up and top-down processing factors influence processing abilities. Furthermore, the findings suggest that older individuals have more difficulty processing linguistic information particularly when speech information is presented at a fast rate and contains reduced contextual cues.

Several more recent studies related to speech recognition, processing speed and aging (Schneider et al., 2005), and neurobiologic changes and aging (Finkel, et al., 2007; Rabbitt, et al., 2006) are also pertinent to address. Similar to Gordon-Salant and Fitzgibbons (2001), Schneider et al (2005) conducted a series of three experiments in which they also used modified R-SPIN sentences. The R-SPIN sentences were altered by speeding up the presentation of the material. This speeding up process was accomplished by removing various segments of the sentence material. Portions of sentences were altered by either: deleting the steady-state portion, deleting every third 10 ms segment, and/or deleting every third amplitude value from the material. These three speeded conditions were used to assess interactions between aging and processing speed and of cognitive slowing and/or auditory degradation. First, the material was altered to create sentences with: 1) “shifted energy into higher frequencies”, 2) more rapid transitions, and 3) reduced silent intervals (i.e., “gaps”) (p. 263). These segmental, timing, and amplitude alterations resulted in the sentence material being speeded by one, one and half, and two times that of normal presentation speed. These alterations created sentences that allowed for five variations of the material to be presented in all three experiments in the following manner: 1) R-SPIN material delivered to participants at a normal speech rate (i.e., “un-speeded condition” first condition where no alterations to the sentences occurred and average speech rate was 216.4 wpm); 2) presentation of the material at 33% time-compressed rates (i.e., second, third and fourth speeded conditions where average speech rate was 324.6 wpm); and 3) presentation of material at 50% time-compressed rates (i.e., fifth speeded condition where the average speech rate was 432.8 wpm). For the fifth speeded condition, duration of sentences was cut in half, creating a time-compression ratio of two times the normal speech rate relative to the rate presented in the first condition. Twenty-four participants (12 younger and 12 older) were recruited for each experiment. Even though all participants were noted as having normal hearing (i.e., thresholds less than or equal to 25 dB HL from 250-3000 Hz), on average the older adults demonstrated hearing sensitivity 8-10 dB poorer at frequencies below 2000 Hz and up to 40 dB poorer from 2000-8000 Hz when compared to younger individuals. Because of this difference in hearing, the researchers incorporated different levels of background noise to establish equivalent performance for both groups relative to low-context words presented in the first condition. Thus, all speech materials were presented at a signal-to-babble ratio of +3 dB for the younger participants and +8 dB for the older participants. Each participant listened to all sentences within the three speeded speech conditions and upon hearing the entire sentence was asked to repeat back the last word in each sentence and indicate whether or not that word was predictable based on the sentence context. Overall, results from these experiments revealed that when contextual information was available (i.e., as in the first condition), both groups were able to accurately predict the last word of the sentence. Thus, presentation of the material at differing SNRs was effective in matching the performance of the groups. Relative to speeded conditions, the older group demonstrated significantly poorer word recognition abilities for low and high content sentences when every third segment of the signal was removed (i.e., 33% time compression). However, when the material was speeded by keeping the transitional information intact, there were no significant differences in performance between the two groups for the low context sentences, and slightly better performance by the older group for the high-context material. Furthermore, even when speech was speeded by 50% (i.e., two times the normal rate), no performance differences between the younger and older groups for low or high context sentences was observed. In general, these results demonstrate an interaction between age and processing speed of time-compressed sentence materials. Furthermore, these results provide additional support of perceptual deficits exhibited by older adults as being related to declines in temporal processing. In this study, age did not impact speech identification for un-speeded or 50% time-compressed speech (i.e., time compression by speeding speech by two times the normal rate). In addition, these results do not support an aging and cognitive interaction as performance scores for accurately identifying the last word of the sentences were 89% and 82% for the younger and older groups, respectively. However, the Schneider et al. (2005) study highlights the importance of the way in which speech is speeded (i.e., 33% time compression by removing every third segment) as their findings did implicate that age-related changes in perceptual processing play a role in the decline of processing speed for the elderly participants in their study for that condition.

Recently, evidence from cortical imaging has been generated that supports functional age related perceptual and attention decline in speech recognition abilities. Age-related functional and structural changes in the brain have been linked to the amount of gray matter within Heschl's gyrus in the temporal lobe as well as increased brain activity within the anterior cingulate cortex in the frontal lobe relative to word recognition performance and accuracy of response (Harris et al., 2009). As technology has advanced, the primitive notion of a unitary system for the processing of attention has been abandoned in favor of quantifiable evidence supporting involvement of multiple neuronal processing areas.

In 2006, Rabbitt et al. conducted a study in which they examined age-related changes in brain volume and blood flow as potential factors in age-related processing speed and cognitive declines. Sixty-nine older adults ranging in age from 62-85 years old underwent cognitive testing of general fluid intelligence (gf), processing speed, memory, and executive functioning skills. During a six week time-frame, a battery of ten cognitive tests were administered and all participants also underwent magnetic resonance imaging (MRI) brain scans. The investigators were especially interested in examining whether age-related changes in brain volume and blood flow were related to processing speed and intelligence and may be linked suggesting a causal relationship between these factors. Results were analyzed to specifically determine whether: 1) individual differences in brain volume and blood flow could be determinants of overall cognitive abilities, with a particular interest in the effects on processing speed and gf, 2) individual difference in calendar age contributed to variance in performance on cognitive measures, and 3) whether similar or different patterns of associations could be determined from brain volume and blood flow with tests of processing speed and gf. Measured differences in brain volume, blood flow, and cognitive abilities were reported as being good indicators of processing speed and executive function. In addition, on average, brain volume and blood flow provided a larger percentage of variance on measures of processing speed. Thus, these data support an association between brain volume, blood flow, and processing speed for predicting test scores relative to neurodegenerative and cognitive processes. In general, performance on all tests declined with an increase in age, and age-related variance in test scores and age-related variance for brain volume were significant predictors for all cognitive test scores. Furthermore, blood flow was also a significant predictor of performance for all tests other than for the "crystallized fluency test and the memory of objects and locations tests" (p. 553). However, after age had been accounted for, brain volume and blood flow were only significant predictors for performance on one processing speed test (i.e., letters-digit coding). Therefore, results indicate that brain volume and blood flow reflect more of the age-related variance for performances of processing speed rather than on the other cognitive scores. Furthermore, neither brain volume or blood flow was related to scores on intelligence tests. These results led the authors to conclude that changes in brain volume and blood flow were significant markers for measures of aging predominately related to processing speed and only weakly associated with intelligence.

In further support of the relationship of processing speed and aging, Finkel et al. (2007) used "*dual change score models* (*DCSM*)" in which a "leading" variable can be identified and that variable can then be examined to determine if it affects changes occurring in a related variable (p. 558). Specifically, researchers analyzed verbal, spatial, memory, and speed of processing abilities. Finkel et al. (2007) noted that some studies provide evidence that "perceptual speed" is primarily responsible for aging effects in areas such as "general knowledge and verbal fluency", while other studies found "speed and memory" were the main factors related to changes in cognitive abilities (p. 559). In Finkel et al. (2007), participants were twins ranging in age from 50-88 years old. Longitudinal measures of aging on four cognitive factors (i.e., verbal, spatial, memory and speed of processing) were used to examine if any one of these factors would indicate which one was the primary component responsible for age-related declines in cognitive abilities. Results were based on univariate and bivariate dual change score models (DCSM) analyses. Univariate results revealed that there was an overall decline in cognitive abilities on all four measures with age for individuals from 50 to 89 years old. The most prominent decline was related to spatial and speed processes. The bivariate DCSM results compared the dynamic relationship between the two-component intelligence (TCI) theory of general intelligence abilities (i.e., spatial versus verbal abilities) related to the age-related processing speed theory. Results from the DCSM analysis did not support the TCI theory and revealed that spatial abilities were not indicators of verbal abilities. However, bivarate DCSM results did support both the Salthouse (1996) processing theory of aging and the findings of the Rabbitt et al. (2006) study. Finkel et al. (2007) reported that processing speed was found to be the leading indicator for age-related changes in spatial and memory (fluid) abilities. In addition, correlation analyses revealed that processing speed, spatial, and memory factors were all moderately correlated with age (i.e., correlations of -.57, -.45 and -.41, respectively). However, of the three factors, processing speed had the strongest correlation with age. Thus, results from Finkel et al. further support the association between processing speed and aging.

Auditory Training Abilities in Older Adults

Auditory perceptual learning.

For older adults with hearing loss, auditory training and/or hearing aid use might improve speech perceptual abilities. *Perceptual learning* is a phenomenon that has been investigated by many different researchers from several different fields. The study of perceptual learning dates back as far as 1899 when it was first described in the literature relative to Morse code training (Watson, Miller, Kewley-Port, Humes, & Wightman, 2008). Perceptual learning is formally defined by Lakshminarayanan and Tallal (2007) as "practice or experience driven improvement in performance as measured by an individual's response to a particular stimulus" (p. 263). Perceptual learning occurs when a measurable enhancement in abilities can be observed as a result of practice on a designated stimulus. *Auditory learning* has been defined by Moore and Amitay (2007) as "any change in a listener's ability to perform an auditory perceptual task contingent upon observed or known experience" (p. 100). Auditory perceptual learning has evolved from a simple concept related to improvement in auditory skills, to being an area of research with theory based concepts, models, and formal definitions. Recent research on perceptual learning is conducted with a variety of auditory, visual and somatosensory experiments in humans and animals (Atienza, Cantero, & Dominguez-Marin, 2002), with most models of auditory perceptual learning based on research in visual perceptual learning. Over the past century, perceptual learning relative to vision (Ahissar & Hochstein, 1993; Gilbert, 1994) and audition (Atienza et al., 2002; Gibson, 1963; Hawkey, Amitay & Moore, 2004; Moore, Amitay & Hawkey, 2003) has been described in the literature.

One component of perceptual learning is "*procedural learning"* which is described by Hawkey et al. (2004) as referring to performance improvement on a perceptual task due to learning the procedure of the task (p. 1055). Some researchers further break down procedural learning into task learning and procedure learning. Ortiz and Wright (2009) propose that perceptual learning includes *stimulus learning, task learning, and procedure learning*. Stimulus learning is attributed to learning specific feature values of training stimuli. In contrast, task learning refers to learning what perceptual judgment is needed to perform the task and procedural learning reflects learning of associated characteristics of training including training setting, method for testing, response required, and tactic for completing the task (Wright & Shang, 2009). Some have argued that perceptual performance improvement that occurs early in the training process may be a result of one learning the procedure (i.e., task and procedural learning). Therefore, research studies typically implement a familiarization period to reduce the effect of procedural learning (Hawkey et al., 2004; Moore et al., 2003).

Hawkey et al. (2004) examined procedural and perceptual learning during early learning on a two-interval, two-alternative forced choice (2I-2AFC) frequency discrimination task. In their experiment, 80 normal hearing adults ranging in age from 20-40 years old were divided into four training groups with 20 participants per group. Groups one and two both received frequency discrimination training, (i.e., same stimulus feature but using different procedures). Group one participants were trained on a 2I-2AFC task (i.e., Which tone is higher?) whereas group two participants received training on an AXB task (i.e., Does tone X match the pitch of the 1st or 3rd tone?). Group three participants received training on a 2I-2AFC intensity discrimination task (i.e., Which tone is louder?) with the same procedure as group one but different stimulus feature. Group four participants received training on a 2I-2AFC visual discrimination task (i.e., Which stimulus has greater visual contrast?) with the same procedure as group one but a different stimulus feature and modality from group one. Participants underwent Test Block one on a 2I-2AFC frequency discrimination task. Following a short break, participants underwent Test Block two on the 2I-2AFC frequency discrimination task. Hawkey et al. proposed that if early learning during the initial training block is mostly perceptual, then groups one and two would show similar and small improvements in performance from Test one to Test two because they had already experienced perceptual learning on frequency discrimination during the initial training block. In contrast, groups three and four would show larger improvements between Test one and Test two performance because Test one would offer them a first experience to learn frequency discrimination. This finding was reported and it indicated that early learning was predominately perceptual and not procedural. Hawkey et al. concluded that early perceptual improvements might be missed if investigators use extended pre-training as a means for restricting or limiting procedural learning.

The complexity of a perceptual task impacts the timeframe in which significant perceptual improvement occurs. As little as 20 minutes and up to two hours of training on interaural-timing discrimination tasks (Wright, 2001; Ortiz & Wright, 200) and less than 40 minutes of training on frequency discrimination tasks (Hawkey et al., 2004) results in performance improvements for young normal hearing individuals. This is significantly less training than that reported by Leek and Watson (1988) in which 17-20 hours of training were needed in order for their young normal hearing participants to identify more complex tonal patterns. In the Leek and Watson (1988) study, sequences of three-tonal patterns that varied in frequency and duration were used in order to investigate characteristics of auditory perceptual learning related to 1) recognition of temporally complex tonal sequences and 2) obtain data regarding the time course of improvements for stimuli identification. Five normal hearing subjects ranging in age from 20-35 years old were trained to learn the tonal patterns as four segments. A simple standard base of three-tones was constructed into four short patterns to produce the easiest level of identification. The length and complexity of learning the patterns increased relative to frequency and segment (i.e., one-segment = three-tonal patterns x one frequency, segment two = three-tonal patterns x two frequencies, segment three = three -tonal patterns x three frequencies and segment four = three-tonal patterns x four frequencies) for a total of 12-tonal patterns. The tonal frequencies ranged from 300-3000 Hz with the duration of each segment being from 135 ms - 540 ms. The tones were monaurally presented via earphones at 75 dB SPL. Four participants were trained on the two segment patterns, three of the four participants from that training also participated in the three-segment training, and all five participants were included in the four-segment training. Training took place daily in a sound treated room. The minimum amount of training time was six weeks. The participants were required to respond by typing in a digit (one to four) on a computer keyboard that corresponded to the tonal pattern heard. Once a response was entered the correct tonal pattern was displayed on the computer screen and immediate feedback was provided on the screen as to whether the answer was correct or incorrect. The overall amount of training time needed to learn the tonal patterns was between 17-20 hours across tonal segments. In regards to characteristics of auditory perceptual learning, the authors stated 1) there were no acoustical characteristics present that were determined as making the learning of the tonal patterns too easy or too difficult and 2) no two subjects had similar learning patterns, meaning that each participant demonstrated an individualized technique of focused attention for learning the stimuli patterns. Thus, there was no evidence for a specific characteristic/mechanism of auditory perceptual learning as each participant's focused attention for learning the stimuli patterns was accomplished in their own unique way.

Another critical aspect of learning, *generalization,* refers to the "transfer of learning to untrained tasks" (Moore & Amitay, 2007, p. 100) and as "improvement on untrained conditions between pre and post-training testing" (Wright & Zhang, 2009, p. 301). Therefore, generalization occurs as a result of learning not related to the specific task being trained. Research studies indicate that generalization depends on the auditory training task (i.e., frequency discrimination, intensity discrimination, interval discrimination, interaural timing discrimination, duration discrimination, syllable discrimination), duration of training, difficulty of the task, and active versus passive listening (Amitay, Irwin, & Moore, 2006; Karmarkar & Buonomano, 2003; Lakshminarayanan & Tallal, 2007; Moore & Amitay, 2007; Ortiz & Wright, 2009).

Amitay, Irwin, and Moore (2006) examined different auditory training tasks in which the duration, stimulus set, and task difficulty were manipulated to determine how learning and generalization were differentially impacted. In addition, they also wanted to determine if learning of an auditory frequency discrimination task would occur with only passive listening. In their study, Amitay et al. (2006) recruited 120 normal hearing college aged adults to participate in one of ten training groups. Each group had 12 participants that performed a variety of auditory tasks. The training and probe testing consisted of a three-interval, three-alternative forced choice paradigm in which participants were instructed to report the "oddball" tone out of three tones presented (e.g., 1 kHz, 1 kHz, 1.4 kHz) (p. 1448). One group served as controls for the frequency discrimination training and was not exposed to any stimuli but was asked to read a book silently. Three groups were trained using a 1 kHz reference tone on a frequency discrimination task where the comparison frequency tones were adaptively altered in order to establish the 50%, 75% and 95% performance levels, respectively. Three additional groups performed one of the following non-adaptive frequency discrimination tasks; 1) training on tones that differed by 400 Hz, 2) training on tones that differed by 7 Hz, and 3) training in which there was no difference between tones (i.e., 0 Hz difference). To assess transfer of learning from one training task to another, one group underwent adaptive training to establish a 75% performance level on a 4 kHz tone. Finally, to investigate whether stimuli influenced learning without attention focused on a listening task, one group passively listened to a regeneration of stimuli used for a listener from the 75% correct adaptive training group. They were instructed to ignore the auditory stimuli while playing a silent video game (i.e., Tetris). Probe testing on the 3-AFC 1 kHz reference tone frequency discrimination task occurred before training, after block one of training, and after block two of training for all groups except for the control group who received probe testing at half-hour intervals. Learning would be exhibited as a significant reduction in the frequency difference threshold on the probe test. All groups, except for the control group, showed learning from the preliminary probe test to the probe conducted after training block one. There was no further improvement after the second training block. Significant differences were reported for effect sizes across groups. Not surprisingly, the control group did not demonstrate significantly improved frequency discrimination. The group that performed the easy 400 Hz discrimination training task showed significant learning on the probe task, despite all participants performing at ceiling levels on the training task. In other words, they performed a very easy training task and yet still showed learning. Interestingly, the two groups that performed the difficult 7 Hz discrimination task and the 0 Hz (no difference) tasks also had strong learning effects that were comparable to results seen in the other training groups. The group that performed the 4 kHz discrimination training task showed generalization (i.e., improved 1 kHz discrimination). Lastly, the passive listening group also demonstrated significant improvements in discrimination, despite being instructed to ignore the auditory stimuli presented. The results suggest that auditory learning/generalization does occur with variations in stimuli, task, and attention focus. In addition, the results from the passive listening training provides further support for bottom-up and top-down influences on learning and perhaps speaks to a "supra-modal arousal mechanism" involved in auditory perceptual learning/generalization (p. 1447). Simple awareness of stimuli may result in learning. Therefore, a combination of top-down and bottom-up processes throughout the brain (McDowd, 2007; Rinne, Stecker, Kang, et al., 2007) may be contributing to perceptual learning.

In another study related to generalization of auditory learning, Lakshminarayanan and Tallal (2007) provide information regarding how training on non-linguistic stimuli generalizes to linguistic stimuli and how the physical characteristics of the stimuli and the task impact the extent of generalization. Lakshminarayanan and Tallal (2007) also investigated active and passive listening tasks using non-linguistic stimuli. Forty-three normal hearing individuals ranging in age from 18-25 participated in the study. There were two groups per experiment consisting of 19 participants (8 controls and 11 trainees) for experiment one and 24 participants (12 control and 12 trainees) for experiment two. Both experiments had pre and post training test measures relative to discrimination thresholds for the syllable contrast /ba-da/ with stimuli varying along a continuum related to the onset time for the second formant. Control participants only participated in pre and post measures whereas trainees participated in pre-testing, training, and post-testing. This study focused on the training of non-speech sounds with rapid transients. That is, Frequency Modulated (FM) sweeps representative of the formant transition for the consonant portion of the syllable and the steady state part that comprises the vowel portion of the syllable. In the first experiment, listeners heard two frequency modulated sweeping tones. Those two FM sweeps varied in frequency sweep direction (i.e., up or down), duration of FM sweep (i.e., 80 ms, 60 ms, 40 ms, 35 ms, 30 ms or 25 ms), and inter-stimulus interval. Listeners were asked to indicate if the two FM sweeps were same or different. The investigators wanted to determine if training the participants to identify specific non-linguistic acoustic features (i.e., upward and downward FM sweeps) would generalize to discrimination abilities for speech syllables that differ in the same acoustic feature (i.e., the direction of frequency change within formant transition). In other words, they were interested in determining if training from the FM sweeps would transfer to speech syllables that shared the same acoustic characteristics. In the second experiment, the variables of frequency sweep direction, duration, and ISI were varied in stimulus pairs of FM sweeps; however, listeners were only asked to indicate or judge the direction of the FM sweep. Following the FM training condition, there were three test conditions involving the identification of syllable pairs /ba-da/, /ba/-/wa/, /sa/-/sta/. These syllable pairs were chosen as they approximated a specific acoustic parameter relative to the stimuli used during the training condition. The /ba-da/ contrast is similar to the acoustic parameter of formant transition for direction; the /ba-wa/ contrast is similar to the acoustic parameter of formant duration; and the /sa-sta/ contrast is similar to the duration of silence. Training took place over three weeks with pre-testing in the first week, followed by training for 30 minutes a day for five days in the second week and post-testing two days after training was completed during the third week. During pre and post testing syllable discrimination thresholds were established for the /ba/-/da/, /ba/-/wa/, and /sa/-/sta/ stimuli. The response for the participant was to replicate the order of an up or down FM sweep by pressing a designated key or clicking the mouse button. Results from experiment one related to the training for the direction of formant (i.e., FM sweep) in lowering the /ba-da/ threshold revealed a significant improvement in performance post training. Results also indicated that the training group had broader variability in discrimination thresholds than the control group. In addition, correlation analysis for a relationship between pre-test and post training performance was significant. The difference in variability among the training groups led the investigators to offer two additional hypotheses. The first was that those individuals who initially had more trouble in discriminating the /ba-da/ pair demonstrate the most training related gains. As predicted, a correlation analysis for a relationship between pre-test discrimination and threshold gain post training was significant. This led to the second hypothesis that those who initially struggled with discriminating the /ba-da/ pair would also be more challenged by the training and therefore, gain the most from the training. To assess this hypothesis a correlation analysis for a possible relationship between percentage of training completed (slower progression in training and increased errors) and change in post training discrimination threshold was conducted. The correlation failed to reach significance. Results for experiment two were examined to determine generalization from the non-linguistic condition to the linguistic condition (FM sweep training to syllable identification), as well as changes in performance related to the actively attended and judged feature (frequency direction change) versus the ignored acoustic features (i.e., duration and ISI). Analysis using a one-tailed t-test revealed a significant threshold difference for the /ba/-/da/ pair only. The syllable pairs /ba-wa/ and /sa-sta/ did not have significant differences in threshold. Lakshminarayanan and Tallal indicated that because there was a significant threshold difference for the /ba-da/ pair, this result represented a replication of the results from experiment one and supported generalization of training from a non-linguistic stimulus to a speech stimulus. The frequency direction in the FM sweep which was attended to and judged in the training task was most closely related to the /ba-da/ syllable acoustic differences. The other syllables showed no improvement in recognition. The investigators concluded that generalization only occurs for like acoustic features. To assess whether a relationship existed for percentage of training time completed and changes in threshold for the participants in experiment two, another correlation analysis was conducted. The analysis revealed an "inverse correlation" between parameters, indicating that those individuals who demonstrated better initial thresholds did not receive as much benefit from training, as they had smaller changes in thresholds post-training (p. 269). In summary, results from both experiments support the influence of non-linguistic acoustic perceptual training on syllable discrimination thresholds as well as generalization of actively attended acoustic features (i.e., identify upward versus downward FM sweeps). In addition, individuals who initially had more difficulty during training (more errors and slower progress through training) and had poorer discrimination thresholds, had greater performance gains post training, thus suggesting that generalization can occur even when challenging an individual's basic abilities. Although results are indicative of "generalization of non-linguistic auditory perceptual training occurring" (p. 271) they contradict findings presented from Amitay et al. (2006) relative to improvements with passive listening. One reason for this may be due to differences in the stimuli and type of listening tasks. In the Amitay et al. study, stimuli to be ignored were sets of three tones differing only in frequency. In the Lakshminarayanan and Tallal study, the stimuli consisted of tonal sweeps in which listeners were asked to attend to one feature (frequency sweep) and ignore the temporal features (i.e., changes in duration and ISI). These differing results point to the many factors that must be considered when designing and implementing auditory training programs geared toward improving auditory perceptual abilities. The overall empirical evidence collectively demonstrates that both auditory learning and generalization occurs as a result of auditory training.

Results from the above studies as well as electrophysiological studies described below lend support for auditory perceptual theories such as the *consolidation theory*. The term consolidation as described by Wright and Sabin (2007) is the “process where learning a task is attributable to transferring information from short-term memory to long-term memory” (p. 727). According to consolidation theory, improvements acquired during training are reflected at differing time periods post training and this demonstrates transfer of learning and ultimately neural plasticity within the human brain (Ari-Even Roth et al., 2005). In addition, the consolidation related to behavioral improvements is thought to occur from several hours to several weeks post training depending on the difficulty of the task and amount of training received (Atienza et al., 2002). A critical aspect in the consolidation theory pertains to how much training is required before consolidation occurs. Wright and Sabin (2007) purport that training induced learning can only occur when an individual has been exposed to the training task for a certain amount of time. That is, in order for the task to be learned, the training must encompass exposure to a certain number of trials per day as well as occur during some allotted critical amount. Based on this theory, Wright and Sabin (2007) designed a study to establish potential “requirements for learning on basic auditory perceptual tasks” (p. 728). These researchers investigated two general principles; 1) whether carry over in perceptual performance occurred from one training day to the next relative to an allotted critical amount of training and 2) whether training beyond the allotted critical amount was beneficial. In addition, Wright and Sabin (2007) wanted to determine if the above principles specifically applied to: 1) learning measured by improvement in discrimination thresholds for auditory training tasks over consecutive days, and 2) whether any observed critical amount of daily training would be dependent upon a specific task and if so, whether the critical amount could be predicted from within-session performance for the task being trained. Twenty-eight normal hearing listeners with a mean age of 21 participated in this study and were divided into one of four training groups. One group (n=7) trained on a 360 trials per day frequency-discrimination task, while a second group (n=6) trained on a 360 trials per day temporal-interval discrimination task. A third group (n=8) trained on a 900 trials per day frequency-discrimination task and the fourth group (n=6) trained on a 900 trials per day temporal-interval discrimination task. Each group participated in a familiarization session prior to training which included one hour of practice related to a) the laboratory setting, b) the presentation of the frequency discrimination task or the temporal-interval discrimination task, c) the adaptive two-alternative forced choice paradigm, and d) detection threshold establishment in quiet for the following tones: 250, 500, 1000, 2000, 4000 and 8000 Hz, as well as detection threshold for a 1000 Hz tone in forward-and backward masking conditions. The duration of training for all groups was six days and each participant received six to ten training sessions per day. There were some differences in findings related to the two training tasks (i.e., frequency discrimination and temporal interval discrimination). Wright and Sabin (2007) reported significant improvements in mean difference thresholds for the participants in the 900 trials/day frequency discrimination and temporal interval discrimination training groups. However, difference thresholds did not significantly improve for participants in the 360 trials/day frequency discrimination training group, whereas difference thresholds did significantly improve for participants in the 360 trials/day temporal interval discrimination training group. These results suggest that learning a temporal-interval discrimination task can occur with as little as 360 trials per day. These results support the investigators' hypothesis that a critical amount of trials per day are needed in order for improvement to occur. Furthermore, there were no significant daily training improvements for either group. Thus, improvement from one training session was not needed in order for learning to occur across sessions. Wright and Sabin also found that training beyond the critical amount does not yield any additional benefit.

Although training beyond the critical number did not produce further improvement, the investigators suggest the possibility of two separate critical amounts that may be needed in order for the consolidation of information to occur. One critical value relates to the number of listening trials for learning to accumulate over several days, while the other critical value may be the performance level beyond which training is no longer beneficial. Another factor may be related to the level of difficulty for training tasks. Wright and Sabin did report that Ahissar and Hochstein (1997) had previously found that the level of difficulty may be a contributing factor in perceptual learning. The listening task and difficulty level may be related to different neural circuitry engaged in these two different tasks (i.e., engagement of right hemisphere for frequency discrimination and engagement of left hemisphere for temporal discrimination). This notion is strongly supported by electrophysiological (Ari-Even Roth, Rabin, Hildesheimer, & Karni, 2005; Atienza et al., 2002; Tremblay & Kraus, 2002) and neurological imaging studies (de Boer & Thornton, 2008; Gottselig, Brandeis, Hofer-Tinguely, Borbely, & Achermann, 2004; Reinke, He, Wang & Alain, 2003; Wassenhove & Nagarajan) that provide sufficient evidence for neural plasticity as well as specialized hemispheric processing of frequency and temporal information. Wright and Sabin (2007) conclude that based on their results, consolidation may be an “all-or-none process” (p.735). In other words, there may not be any transfer of learning from short-term to long-term memory until a critical amount of training has been completed. A critical number of training trials are needed on a daily basis in order for consolidation and potentially neural plasticity to occur.

The actual amount of training time needed for an individual to demonstrate improvements on an auditory task varies. For example, although relatively little time is needed for training improvements to be shown (i.e., 20 minutes as reported by Wright, 2001), in general, learning acquired during training on a task is affected in that less learning occurs for training durations lasting less than one hour. However, training on basic auditory tasks (i.e., amplitude modulation, interaural level discrimination and interaural timing discrimination) lasting in duration of approximately one hour has been shown to produce task specific learning of that trained auditory task (Wright, 2001). Evidence indicates that generalization of a task does appear to occur during shorter duration training times compared to longer training periods. Therefore, design and length of auditory speech perceptual training programs may impact results based on whether the target goal is learning the training task or generalization of the task (Lakshminarayanan & Tallal 2007; Wright, 2001). Wright found that while shorter training led to smaller improvement, shorter training did lead to generalization. Furthermore, type of auditory learning and generalization that occurs during training is contingent upon length of training (i.e., single session versus multiple sessions) and the training task (Ortiz & Wright, 2009). For example, according to Wright and Zhang (2009), there are multiple training tasks on which generalization of auditory learning has been demonstrated including: frequency discrimination for standard stimuli as well as between the trained and untrained ears; frequency discrimination between training and testing conditions (i.e., task using a standard or roving tone); frequency discrimination for fundamental frequency; temporal-interval discrimination for untrained frequencies as well as for trained temporal intervals for multimodal generalization (i.e., auditory system, motor system, somatosensory system); and spatial interaural level and interaural timing differences. Although partial generalization only occurred in some of the training tasks (i.e., across untrained frequency stimuli, across untrained frequency durations, across untrained temporal-intervals and for amplitude-modulation rate discrimination for fast rates), this information adds to the mounting evidence in support of generalization and auditory learning within the brain as a result of auditory training (Wright & Zhang, 2009).

Neural changes following practice of frequency discrimination tasks have also been investigated. In evoked potential and mismatch negativity (MMN) studies, improved waveform amplitudes (i.e., larger) for non-speech stimuli have been recorded for normal hearing participants after six minutes for practicing simple and complex tonal pattern discrimination (Gottselig, et al., 2004; Hawkey et al., 2004), to approximately one hour for frequency discrimination (Brattico, Tervaniemi, & Picton, 2003), to 36 and 48 hours post training on two complex auditory discrimination tasks (Atienza et. al, 2002). These electrophysiology studies provide empirical evidence in support of the consolidation theory. Collectively, these studies support the transfer of information into long-term memory in a relatively short timeframe (i.e., six minutes to 48 hours).

Consolidation is further supported by results from Atienza et al. (2002) in which fast and slow neuronal changes were assessed relative to the amount of contribution each component plays in perceptual learning. In their study, ten normal hearing adults ranging in age from 18 to 30 participated in training and testing on discrimination of tonal frequencies. Electrophysiological data from Atienza et al. (2002) consisting of cortical evoked responses (i.e., N1-P2 complex and mis-match negativity (MMN) data) were used for measurement of neural changes along with behavioral reaction time measures for response to occasional deviant stimuli. Stimuli were presented as two complex auditory patterns designed with the first auditory pattern being the presentation of a sequence of tones (i.e., eight tones presented at different tonal frequencies such as: 720 Hz, 500 Hz, 638 Hz, 1040 Hz, 117 Hz, 565 Hz, 815 Hz and 920 Hz) and the second auditory pattern being an oddball stimulus (i.e., deviant frequency of 650 Hz) that was presented every sixth tone in replacement of the standard 565 Hz tone. The auditory patterns were pseudorandomly binaurally presented to each participant via insert earphones. Participants were trained on discriminating between the two auditory patterns during one training session. Each time a deviant tonal frequency was heard the participant was to respond by quickly pressing a key. Behavioral changes were reported as faster response times, and neurophysiological changes were reported as increased MMN and P2 amplitudes, respectively. Results from the training and testing were indicative of fast neural changes (i.e., preattentive and attentive early perceptual processing) being associated with an increase in amplitude for the mis-match negativity (MMN) component during training. In contrast, slow changes (i.e. consolidation process or perceptual awareness) occurring post-training were related to an increase in the P2 amplitude and an additional post training increase in MMN amplitude. These results not only support the consolidation theory, but also indicate that perceptual learning occurs in two stages as the fast neural changes were evident during training whereas the slow neural changes were evident several hours after training (i.e., 24-48 hours). These slow neural changes may evidence top-down processes that contribute to improvement in short and long term memory and enhance performance for individuals participating in auditory training. Results from this study showed significant changes in both the behavioral and neurophysiological responses to non-speech tonal stimuli from between 12 and 48 hours post training.

Another key factor in perceptual learning and training relates to the preservation of improvement post training. Following a single highly focused training session in which young, normal hearing individuals trained for approximately one hour on tasks involving consonant-vowel (CV) discrimination in noise, Ari-Even Roth, Kishon-Rabin, Hildesheimer, and Karni (2005) found performance improvements four-to-six hours post training. Furthermore, these training related gains were still present one and six months post training which not only supports the notion of the consolidation theory (Roth, et al., 2005; Wright & Sabin 2007) but also supports preservation as being a critical perceptual learning element.

The preservation of perceptual learning post training is evident from electrophysiological and magnetic resonance imaging studies for non-speech and speech stimuli. These types of studies reveal plasticity in the human brain (Brattico, et al., 2003; Gottselig, et al., 2004; Reinke et al., 2003; Roth, et al., 2005; Wassenhove & Nagaajan, 2007) as well as in the rat brain for frequency discrimination and auditory temporal rate training (Bao, Chang, Woods, & Merzenich, 2004; Polley, Steinberg, & Merzenich, 2006). Collectively, these studies provide empirical evidence for perceptual learning as occurring within disparate regions of the brain to include: the auditory cortices (i.e., primary A1 and secondary A2 areas) (Bao et al., 2004; Gottselig et al., 2004; Polley et al., 2006; Reinke et al., 2003; Wassenhove and Nagaajan, 2007), the left inferior frontal cortex (Wassenhove and Nagarajan, 2007), the right temporal lobe relative to non-speech stimuli (Gottselig et al., 2004), and left temporal lobe relative to speech stimuli (Gottselig et al., 2004; Reinke et al., 2003). The various locations within the brain that demonstrate plasticity provide additional support for top-down and bottom-up mechanisms working in conjunction for enhancement of auditory perceptual learning in both animal and human studies (de Boer & Thorton, 2008; Polley et al., 2006; Wassenhove & Nagarajan, 2007). That is, the above studies demonstrated that even though training was specific to a certain task (i.e., attending to a frequency or intensity tonal stimuli or speech (CV) stimuli), data from behavioral (auditory performance) neuroimaging (magnetoencephalography and MRI) physiological (click evoked otoacoustic emissions), and electrophysiology (ABR) measures revealed plasticity changes as a result of perceptual learning. The empirical data reported from the above studies are indicative of the benefits an individual may receive from auditory training.

Noted improvements are further supported by research showing brain changes as a result of auditory training. In addition to the above reported results from auditory training, research also indicates that changes in electrophysiological measures were evident following auditory training (Kricos, & McCarthy, 2007; Tremblay, 2007). An important outcome of these electrophysiology studies is the overall conclusion that the auditory system in adults is adaptive and that plasticity does take place.

Thus, a promising outcome of auditory training, based on behavioral and electrophysiological analysis, is that of neural plasticity. Behavioral outcome measures following auditory training programs have shown that auditory skills improve including temporal processing, auditory discrimination, auditory closure, as well as binaural separation and integration (Musiek, Shinn, & Hare, 2002). Unlike the peripheral mechanism, the brain has the capability of changing and reorganizing based on neural responses to external and internal stimulation (Musiek et al., 2002). This phenomenon is known as neural or auditory plasticity (Musiek et al., 2002; Jirsa, 2002). Furthermore, because auditory training is designed to target the brain, neural plasticity is especially apparent in studies conducted using auditory evoked potentials (Musiek et al., 2002). Jirsa (2002) reports on results from electrophysiological studies that provide evidence indicating that neural changes (i.e., improved latency and amplitude) occur before behavioral changes (i.e., subjective response to an auditory signal). As such, Jirsa purports that electrophysiological measures are critical elements to include as part of the rehabilitation process. Furthermore, electrophysiological measures, including auditory brainstem response (ABR), middle-latency response (MLR), long-latency (N1-P2 complex), mis-match negativity (MMN), and event-related-potentials (P300) show compelling evidence to support the clinical relevance of the incorporation of electrophysiological measurements as an efficacious management tool for auditory as well as cognitive neural changes (Jirsa, 2002).

Auditory training.

Auditory training is defined as “aural rehabilitation methods designed to maximize the use of residual hearing by structured practice in listening” (Stach, 2003, p. 33). Auditory training programs may incorporate use of either analytic (consonant and vowel identification in nonsense syllables or isolated words) and/or synthetic (phrase or sentence) materials (Tye-Murray, 2004). The objective of the analytic training approach is to have an individual identify acoustic speech cues in nonsense syllables and then progress to identification of isolated words. In synthetic training, the individual is trained in the identification of related words, sentences, and phrases so that they can use meaning and contextual information (Tye-Murray, 2004). Depending on the overall goal of auditory training, these two methods can either be used in conjunction with one another or separately. When considering the use of auditory training, it is imperative to consider all characteristics of the individual such as; degree of hearing loss, cognitive abilities, general health status, motivation and self-reported hearing handicap/disability, as well as characteristics of the training including; type, modality (i.e., whether visual cues are included), method, procedure, stimuli, duration, frequency of sessions, and feedback offered. Type of training generally refers to whether stimuli constitute open or closed set tasks. In open-set tasks; which are the most difficult type, an individual does not have knowledge or familiarity of the training materials, while in closed-set tasks the individual does have knowledge of the training materials. Different presentation modalities including unimodal or bimodal can be used in auditory training methods and programs (Blumsack, Bower, & Ross, 2007). Unimodal refers to tasks involving either auditory only (A), or visual only (V) presentation, while bimodal refers to auditory-visual (AV) presentation. Presentation modality is of importance as normal and hearing impaired listeners typically show best task performance in the auditory-visual mode. The use of vision for perceiving a message can be even more critical to one's understanding when in noisy environments (Wingfield, 1996).

While auditory performance is an important metric for measuring change with auditory training, another characteristic related to the individual with hearing loss that may change with auditory training is self-reported hearing handicap or disability. The World Health Organization (1997) defines the functions of *hearing participation* and *hearing activity* rather than using the older terms *hearing handicap* and hearing *disability*. However, the latter terms persist. Hearing handicap (or hearing participation restriction) describes how hearing loss affects the social, academic, vocational, emotional, and speech and language characteristics of an individual. Hearing disability (or hearing activity limitation) describes activities that are limited or prohibited by the hearing loss. According to statistical information provided by the WHO, as of 2001, an estimated 250 million people world-wide had a disabling hearing impairment of moderate severity or greater (Heine & Browning, 2002; http://search.who.int/search?ie=utf8&site=default_collection&lr=lang_en&client=WHO&proxystylesheet=WHO&output=xml_no_dtd&oe=utf8&q=disabling+hearing+impairment&Search=Search&sitesearch). Furthermore, as previously mentioned, because hearing loss is recognized as the third most common condition in the elderly, there has been an increase in the number of reported self-perceived hearing disability and hearing handicap among this population (Heine & Browning, 2002).

Use of self-reports that specifically measure hearing disability and hearing handicap are critical because they indicate the individual's perception of their real world hearing difficulties. Self-report questionnaires are designed to measure one's perspective relative to everyday hearing difficulties and their impact on social, emotional, and communication status. There are numerous self-report questionnaires available; however, the most common self-report scale used in studies of the elderly is the *Hearing Handicap Inventory for the Elderly* (*HHIE*-standard version; Ventry & Weinstein, 1982), and/or the screening version (*HHIE-S*; Weinstein, 1986). As reported by Palmer, Solodar, Hurley, Byrne, and Williams (2009), the HHIE was developed to measure the “psychosocial effects of hearing loss” in the elderly (p. 341). More specifically, it is a standardized set of 25 questions comprising two subscales with 13 emotional based questions and 12 social/situational based questions relative to hearing loss (Ventry & Weinstein in 1982). The HHIE-S is a ten-item screening version (Lichtenstein, Bess, & Logan, 1988). The American Speech-Language-Hearing Association (1997) recommended the HHIE-S as an assessment tool with normative data for individuals aged 65 and older. Wiley et al. (2000) reported the prevalence for hearing handicap (i.e., scores greater than eight) based on data collected on the HHIE-S for 3,178 adults with normal to moderate hearing loss ranging in age from 48-92 years. The overall prevalence for scores greater than eight was 23% and 14% for men and women, respectively. Prevalence for handicap in individuals in the older age groups (i.e., 60-92 years) ranged between 11 - 31% for women and between 24 – 38% for men. Furthermore, Wiley et al. (2000) also stated that hearing handicap among those with differing degrees of hearing loss were approximately: 8% for mild hearing loss, 29% for moderate hearing loss, and 65% for severe hearing loss (p. 69). These results indicate that men perceive themselves as being more hearing handicapped than women, older individuals have higher prevalence for perceived hearing handicap, and the greater degree of hearing loss, the higher the perceived handicap. Studies which have used the HHIE or HHIE-S have reported on correlations between audiometric thresholds and self-perceived hearing loss (Palmer et al., 2009; Wiley et al., 2000), impact of hearing loss on quality of life (Dalton et al., 2003), outcome measures post training (Sweetow & Henderson Sabes, 2006; 2007), as well as predictors for improvement from auditory training (Henderson Sabes, & Sweetow, 2007). Results from studies using audiometric thresholds and HHIE scores, generally present correlations between .27 (Henderson Sabes, & Sweetow, 2007) and .61 (Palmer et al., 2009). Low to moderate correlations here suggest that hearing loss does not closely correspond to degree of hearing handicap. Of greater interest are the promising results from auditory training programs that reflect improved HHIE scores (Henderson Sabes, & Sweetow, 2007; Sweetow & Henderson Sabes, 2006). As practitioners build their auditory training regimens, consideration should be given to use of psycho-social measures as they appear to offer a means for measuring training-related improvements.

Sweetow and Palmer (2005) examined the efficacy of individual auditory training programs for adult listeners with hearing impairments and concluded that the use of synthetic auditory training *might* help those with hearing impairments with speech understanding in noise as well as facilitate the use of active listening strategies resulting in “improved psychosocial function” (p. 501). This is important because those with hearing impairments, especially the elderly, perceive themselves as having hearing handicaps or disabilities due to their hearing loss (Dalton, Cruickshanks, Klein, et al., 2003; Gordon-Salant, 2005; Karlsson Espmark, Rosenhall, Erlandsson, & Steen, 2002; Wiley, Cruickshanks, Nondahl, & Tweed, 2000), and or dual sensory loss (Heine & Browning, 2002) which may lead to a disruption in their social activity.

In recent years, the use of auditory training as a management tool to help individuals with hearing loss improve their communication abilities has received renewed attention with the possibility of computer-based training. Electrophysiological and behavioral measures indicate that individuals with hearing loss who use hearing aids and cochlear implants benefit from auditory training (Fu & Galvin, 2007; Henderson Sabes & Sweetow, 2007; Miller & Watson, 2008; Stecker, Bowman, Yund, et al., 2006; Sweetow & Henderson Sabes, 2006; 2007; Tremblay, 2005; Woods, & Yund, 2007).

In a study using hearing aid participants and nonsense syllable training, Woods and Yund (2007) investigated the effects of perceptual training on speech processing for individuals with high frequency hearing loss. The participants were male hearing aid users ranging in age from 50-80 years, with gradually sloping mild-to-moderate symmetrical high frequency hearing loss. These participants were divided into two groups; a) immediate training group which began training within one week of initial hearing aid use and b) delayed training group which were viewed as untrained controls until they began the training portion eight weeks post hearing aid fitting. Both groups used a computer-based research training program at home for 30-70 minutes a day, five days a week for eight weeks. The task was to identify syllables chosen from the City University of New York *Nonsense Syllable Test* (*NST*) (Resnick, Dubno, Hoffnung, & Levitt, 1975) presented in low-frequency noise. The stimuli consisted of nine unvoiced consonants (/ch/, /f/, /h/, /k/, /p/, /s/, /sh/, /t/, and /th/) and three vowels (/a/, /i/, /u/) presented in consonant-vowel (CV) format, and. nine voiced consonants (/b/, /d/, /g/, /m/, /n/, /ng/, /TH/, /v/ and /z) presented in vowel-consonant (VC) format spoken by two male and two female speakers. The noise adaptively varied by +1or -1 dB signal-to-noise ratio (SNR) increments based on correct or incorrect responses, respectively. In addition, to determine the efficacy of training, participants were tested with the NST material presented by all four speakers in 0 and +10 dB SNR conditions. Mean unaided NST scores were compared to mean aided NST scores obtained immediately after initial fitting of hearing aids and changes were indicative of significant improvements of six percent (i.e., 3.8 dB SNR improvement by hearing aid use alone). Testing for those in the immediate perceptual training group occurred at one, two, four, and eight weeks during training. From pre-training to the eight weeks measure, a significant improvement of approximately ten percent (i.e., 6.4 dB SNR improvement) on the NST scores was noted (Woods & Yund, 2007, p. 114). Results for the delayed training group for perceptual training were indicative of significant improvements of approximately nine percent when comparing pre-training NST scores to the eight week NST scores (i.e., 5.8 dB SNR improvement) (Woods & Yund, 2007). In addition, both immediate and delayed training groups retained their improved scores eight weeks post-training. The researchers examined error patterns and found that perceptual training was helpful in improving the identification and discrimination of previously difficult phonemes (based on pre-testing) while amplification was beneficial for phonemes that were previously easy to discriminate. Furthermore, these results coincide with results from Sweetow and Henderson Sabes (2007) relative to the significant improvements in SNR as well as retention of gains achieved from training.

Additional support for auditory training of speech in noise comes from Burk, Humes, Amos, and Strauser (2006) and Stacey and Summerfield (2008). Burk et al. (2006) examined speech identification of lexically hard and lexically easy words in speech-shaped noise for 16 young normal hearing adults (20-30 years old) and seven older adults (65 to 75 years old) with binaural mild to moderate sensorineural hearing loss. Seven 60 minute training sessions took place over a two-week period. Presentation of the material was to the right ear only with an overall signal to noise ratio (SNR) of 0 dB for the younger listeners and a +5 dB SNR for the older listeners. The difference in SNRs was determined to be a means for: 1) eliminating floor effects in the older adults and 2) to perceptually equate performance between the younger and older adults. One purpose of this study was to determine if older adults with hearing loss were able to improve their speech identification in noise using an open and closed set word-based training protocol. A second objective was to establish if the word-based training protocol would lead to generalization for novel speakers as well as to sentence level materials. Burk et al. (2006) used a list of 150 monosyllabic "AB words" for word identification testing pre and post training (p. 265). For the open-set material, the first 75 words from the list were presented to the participants and they were instructed to write their responses on an answer sheet. For the closed-set material, the second half of the list was presented with the words displayed in alphabetical order on a computer screen. For the closed set condition, the participants were instructed to choose the word using the computer mouse. Results for the young-normal hearing participants revealed significant improvement for word recognition in open and closed set trained and novel words. In addition, the improved performance generalized to novel speakers of the open and closed set words. Results for the older hearing impaired adults indicated a significant improvement in word recognition for both trained and novel words. Relative to the open and closed set responses, significant improvement only occurred for the open set condition. The older adults also demonstrated generalization to novel speakers. Although retention of training benefit on word only identification for older adults did occur, generalization to sentences did not occur. Furthermore, at six months post training, the investigators evaluated the older adults on identification of trained words alone, and trained words in sentences to determine whether benefits were retained and whether generalization occurred. The older adults' performance level at six months was poorer (i.e., 62.9%) than their performance at the end of the initial training (i.e., 83.5%). However, they did demonstrate significantly better performance (i.e., 62.9%)

relative to their pre-training performance (i.e., 37.6%) for the trained words. Furthermore, only one hour of training was needed in order to restore performance to immediate post training performance levels. The investigators concluded that even though training on words in noise appeared to be beneficial to older adults with hearing loss, the lack of generalization to sentences demonstrates that training on words may not be beneficial for improvement of speech perception in real word communication situations.

Recently, Stacey and Summerfield (2008) conducted a study using 18 young normal hearing adults to investigate the effectiveness of word, sentence, and phonetic training on identification of spectrally distorted speech. All speech material was presented through an eight channel noise-excited vocoder and filtered to produce the distorted speech. These investigators hypothesized that word and sentence level training would have the greatest impact on speech perception. Six participants were randomly selected for the word training, six were randomly selected for the sentence training, and six participants were randomly selected for the phonetic training. Each participant received ten training sessions on ten different days. All speech stimuli were presented through loudspeakers with the participant seated in a single-walled isolation suite. The word training consisted of 200 key words from the *Institute of Electrical and Electronic Engineers* (*IEEE*) sentences in a 2-AFC choice task. The task involved the orthographic presentation of two words on a computer screen. The target word was then presented acoustically and the participant was instructed to touch the computer screen corresponding to the target word. If the response was incorrect the trial was repeated until the participant correctly identified the word. For the sentence training, 300 IEEE sentences were used. None of these sentences were previously used during the word training. The sentence material was presented acoustically followed by six words being displayed on the computer screen. The participant was instructed to touch three key words that were presented in the sentence. Again, if the response was incorrect, the trial repeated until all three key words were accurately identified. For the phonetic training task, the material was based on the auditory training program *Phonomena* (Mindweavers, 2003; Moore, Rosenberg & Coleman, 2005). Briefly, 11 sets of sounds with vowel contrasts of /i/, /e/ or /va/, /wa, /sa/ or /sha/ were used. The training procedure used an AXB 2-AFC protocol where a target sound was acoustically presented followed by two additional sounds. The participant was instructed to choose which one was the same as the target sound. Participants responded by pressing a corresponding key on the computer keyboard. In addition to training, all participants underwent speech perceptual testing which occurred before training (baseline), during training (probe testing) and after training. Testing consisted of the: 1) *Bamford-Kowal-Bench (BKB)* sentence test (Bench, Kowal, & Bamford 1979), 2) *IEEE sentence test*, 3) a *Consonant test* and 4) and a *Vowel test.* For the *BKB* each sentence contained three key words to be used for scoring. The participants were instructed to repeat the words that they had heard presented in the sentence. For the IEEE sentence test, the participant was instructed to repeat the words that they heard presented in the sentence. Five key words were used for scoring. For the Consonant test*,* 20 vowel-consonant-vowel nonsense syllables were orthographically displayed on a computer screen. Participants were instructed to select the consonant heard in the VCV nonsense syllable by touching the corresponding consonant on the computer screen. For the Vowel test, ten h-vowel-d words (i.e., had, heed, hood etc.) were orthographically displayed on a computer screen. Participants were instructed to respond by touching the corresponding word they heard on the computer screen. Results from this study indicated that there were no significant differences in baseline performance across groups. Relative to the participants in the phonetic training group, these individuals failed to demonstrate significant improvement on any of the outcome tests. The sentence training group showed significant improvement for the BKB sentence test and IEEE test materials. The word training group demonstrated significant improvements for the BKB sentence test, IEEE tests, Consonant test, and Vowel test. Thus, the investigators concluded that word and sentence training led to significant improvement on sentence test performance. The investigators concluded that lexical information is important for perceiving distorted speech. Stacey and Summerfield demonstrated that word and sentence training can generalize to the identification of novel sentences. Taken together, these studies provide further empirical data suggesting that auditory training is beneficial for the purpose of improving speech perception. Furthermore, because of these advantageous results, auditory training programs have recently gained attention as a viable tool in the aural rehabilitation of older adults with hearing loss.

Advances in technology have led to the development of new computer-based auditory training programs that are available for use with older adults with hearing loss such as the: *Listening and Communication Enhancement* (*LACE*) program (Sweetow & Henderson Sabes, 2006; Neurotone, Inc., 2007-2009; www.neurotone.com), *Internet Computer Assisted Speech Training* (*i-CAST*) (Fu, 2007) and *Internet Speech Testing Assessment and Rehabilitation* (*i-STAR*) (Fu, 2007; Tigerspeech Technology, Innovative Speech Software, 2005-2006; www.tigerspeech.com), and the *Speech Perception Assessment and Training System* (*SPATS*), (Miller, Watson, Kistler, Preminger, & Wark, 2008; Miller, Watson, Kistler, Wightman & Preminger, 2008; Miller, Watson, Kewley-Port, et al., 2008; Communication Disorders Technology, Inc.; www.comdistec.com). These programs offer the potential for state-of-the-art home based auditory training for adults with hearing loss. Each of these programs will be discussed as they were given consideration for use and/or were selected for use in the current investigation.

Sweetow and colleagues (2004; 2006; 2007) have offered research supporting the benefits of the combined auditory perceptual and cognitive training in LACE^{TM}. Sweetow and Henderson Sabes (2006; 2007) observed that individuals with similar hearing losses and who had hearing aids did not report receiving the same benefit from their devices. According to Sweetow and Henderson Sabes (2006; 2007), this observation is because these individuals need to optimize integration of processing skills such as, "cognition, auditory memory, auditory closure, auditory learning, metalinguistics, pragmatics, semantics, grammatical shape, localization, visual cues, repair tactics, and effective interactive communication strategies" (p. 133-134) in addition to being amplified. Furthermore, because hearing aids are designed for audibility, simply wearing a hearing aid may not be beneficial with overcoming frequency and temporal resolution deficits. Thus, it is important to integrate the concept that hearing and listening should go hand-in-hand in that, "hearing requires audibility" (p. 134) and listening requires an integration of "attending, understanding, remembering and intention" (p. 375). As reported by Kiessling et al. (2003), there is a hierarchical process related to communicating that may be altered in the elderly population due to hearing loss. These processes are outlined as; "hearing, listening, comprehending, and communicating" (p. 2S93). Hearing is described as a "passive function" for perceiving sound; listening is described as "hearing with intention and attention"; comprehending refers to a "uni-directional" process that involves "reception of information, meaning or intent"; and communicating refers to a "bi-directional" process between two or more people where "information, meaning, or intent is exchanged between the individuals (p. 2S93).

Top-down and bottom-up processes reportedly are challenged in LACE^{TM} training such that improved listening skills may lead to enhanced communication and comprehension.

Version one of the LACE^{TM} program (Sweetow & Henderson Sabes, 2007) is an interactive, adaptive auditory training computer program that can be used by individuals with or without amplification in the comfort of one's home. There are two main training categories; “degraded speech and cognitive skills”, with periodic communication strategy tips presented throughout the training. The training material for the degraded speech component consists of sentences within a few designated topics (i.e., health, money or exercise; Potpourri) (Sweetow & Henderson Sabes, 2006; 2007). A training topic is selected at the beginning of each training session by the trainee in order to allow for the use of contextual cues with general topics. The training sentence stimuli were spoken and recorded by men, women, and children. The suggested therapy regimen was 30 minutes per day for five days a week over a four week period, with presentation levels set at the most comfortable listening level for the individual. All LACE^{TM} training exercises require listeners to perform a listening task (e.g., identify a sentence heard in babble), read the correct answer on the computer screen, and then indicate their accuracy on the task (i.e., how many words they accurately identified). Seventy percent of the training exercises are conducted using degraded speech. There are three conditions of degraded speech: 1) time-compressed (TC) speech which is used to simulate rapid speech (TC task), 2) background speech-in-babble noise (SB task), or 3) single competing speaker (competing speech (CS task). The difficulty level on the task adapts such that if a listener reports accurate identification for a set of sentences, the listening difficulty increases on the next sentence presentations (i.e., louder competing noise or greater time compression). In contrast, if the listener reports incorrect sentence identification, then task difficulty is reduced (i.e., lower competing noise or lower time compression). In addition to the above degraded speech training materials, the LACE^{TM} program also offers "missing word (MW) and target word (TW) cognitive training exercises" (p. 136). Fifteen percent of the LACE training is based on target word exercises for training related to auditory memory. In this training, a target word is visually presented to the patient. After reading the word, the patient then listens to a sentence in quiet in which the target word is one of the words. The patient's task is to select the word in the sentence that precedes the target word from a visually presented set of words. After the patient has had consecutive correct responses; the level of difficulty increases. The level of difficulty varies with the length of the sentence and by the order of the presentation of the task. As an example of the latter, the sentence is presented first, followed by the target word. The TW task requires the patient to use short-term memory with varying levels of task load. When the patient has had two consecutive correct responses; the difficulty of the task increases to include the presentation of two to six sentences and target words. If the patient misses two in a row, the training difficulty is decreased in the same manner as above. The other cognitive training task within LACE^{TM} is that of missing words which reportedly relies on cognitive speed of processing and linguistic/contextual cues. This is an auditory-closure task with one word in a sentence masked out by a sound (i.e., car horn, ringing telephone, etc.) and the listener asked to identify the missing word as quickly as possible. As previously mentioned, written communication strategy tips are incorporated throughout the LACE^{TM} training sections. The communication strategies constitute approximately 15% of the training and include about 150 aural rehabilitation or interactive communication strategies that are periodically displayed on the screen throughout the training sessions. The LACE^{TM} program also offers the patient with graphical data showing daily progress from the beginning of training.

Additionally, data for each client can be tracked and electronically transmitted to a HIPAA compliant website which provides the audiologist a means for monitoring the patient's progress.

Sixty-five adults ranging in age from 28 to 85 years old participated in a study of the effectiveness of a pilot version of the LACE^{TM} program (i.e., version one) (Sweetow & Henderson Sabes, 2006; 2007). Fifty-six individuals were experienced hearing aid users (with the majority, 85%, being amplified binaurally). Nine participants were not amplified. The individuals were randomly placed into two training groups for this study. All participants underwent baseline testing and outcomes measurement using the *Quick Speech in Noise test* (*QuickSin*, version 1.3, Etymotic Research, Elk Grove Village, IL, 2001; Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004) at 45 and 70 dB HL, the *Hearing in Noise Test* (*HINT*, version 6.3, Maico Diagnostics, Eden Prairie, MN; Nilsson, Soli, & Sullivan, 1994) at a 65 dBA noise level with the noise at zero degrees azimuth (Sweetow & Henderson Sabes, 2006; Sweetow & Henderson Sabes, 2007), the *Hearing Handicap Scale for the Elderly* (*HHIE;* Ventry & Weinstein, 1982) or *Hearing Handicap Inventory for Adults* (*HHIA;* Newman, Weinstein, Jacobson, & Hug, 1990), and the *Communication Scale for Older Adults* (*CSOA;* Kaplan, Bally, Brandt, Busacco, & Pray, 1997). Two training groups were established and participants were assigned randomly to each of those groups. Group one began training immediately after the initial testing. Group two served as controls for the first month, and then returned for a second test session prior to beginning the training. Results for pilot version one of the LACE^{TM} study are provided in multiple publications; however, results are consistent throughout publications, therefore only the data set from Sweetow and Henderson Sabes (2007) will be discussed. These investigators reported that both groups (i.e., early trained and later trained) showed significant improvements on the LACE^{TM} training tasks across daily measures as well as on the speech identification and hearing handicap measurements and that there were no significant differences between groups. Specifically, from baseline testing to the end of training, between 84% and 88% of hearing aid users demonstrated statistically significant improvement on scores for the degraded speech task within LACE^{TM}, while between 75% and 80% showed statistically significant improvement on scores for the cognitive tasks within LACE^{TM}. In general, 60% of the hearing aid users had statistically significant performance improvements on all LACE^{TM} training tasks with 83% of the individuals improving on all but one task. Quick Speech in Noise test results at 45 dB HL and 70 dB HL showed that 85% and 75% of the individuals had a signal to noise ratio improvement of 2.2 dB and 1.5 dB. Results from the HINT were not significantly different when comparing pre and post training results and overall variability in HINT scores was considered a factor in this result. Results from the self-report questionnaires indicated that between 63% and 76% of the individuals' scores were improved by 7.5 points on the HHIE and HHIA respectively, and by 0.06-0.14 on the CSOA-attitude scale and the CSOA-strategies scale, respectively. In other words, the average hearing handicap score decreased from pre-training to post-training which was indicative of a significant decrease in handicap (Sweetow & Henderson Sabes, 2006. Relative to the non-hearing aid users, significant differences in scores were only obtained on the speech in babble and competing speech LACE^{TM} tasks. Sweetow and Henderson Sabes (2007) proposed that the lack of improvement on other tasks may be related to the fact that these individuals were younger, had better hearing acuity, and better initial test scores. As far as post-training effects, data obtained four weeks after training indicated that training effects on all measures lasted longer than the initial training period. In addition, the gains made during training were maintained when re-evaluated at eight weeks. However, data collected six months post training from a subset of participants indicated that there was a decrease in scores. Therefore, it was suggested that "periodic booster sessions" may benefit individuals (p. 139).

In the same experiment, Sweetow and Henderson Sabes (2006; 2007) also explored cognitive changes following LACE^{TM} training. A selected group of 27 subjects underwent the *Listening Span Test* (Pichora-Fuller, Schneider & Daneman, 1995) and the *Stroop Color Word Test* (Uttl & Graf, 1997) to evaluate working memory and processing speed, respectively. Listening span significantly improved only after training, suggesting increased working memory span. Stroop Color Word Test processing speed significantly improved only after training, suggesting increased speed.

To further investigate whether outcome measures could be predicted based on results from particular variables demonstrated by participants in the previous mentioned LACE^{TM} studies, Henderson Sabes and Sweetow (2007) performed additional analyses. Correlations between age, hearing loss, and baseline performance were considered as potential factors contributing to improvement in performance. All LACE^{TM} outcome measures (i.e., HHIE, CSOA, and QuickSIN) as well as scores from the LACE^{TM} training components (i.e., degraded speech, and memory) were assessed. Results from Henderson Sabes and Sweetow (2007) analyses indicated: 1) baseline performance on HINT *and* QuickSIN was associated with degree of hearing loss as was the HHIE; 2) age and hearing loss were significantly associated with the amount of time needed in order to complete the training program with older listeners completing the program earlier; 3) age was not correlated with improvement on any test measures; 4) a positive correlation was reported between degree of hearing loss and improvements on the QuickSIN and HHIE; and 5) baseline QuickSIN scores correlated with improvements on the QuickSIN and baseline performance on the HINT was associated with improvements on the QuickSIN (i.e., poorer initial score or greater SNR was related to greater improvement). The investigators did not find any measure that could reliably predict an individual's overall improvement. Participants in the LACE™ training study who had better initial performance did not demonstrate as much performance improvement as those individuals who initially performed more poorly. Although the results from this analysis are specific to the LACE™ training program, they reflect an interest in identifying baseline performance measures that might predict training outcomes. Some research-based auditory training programs, such as the LACE™, have been made available through purchase or internet access.

With the integration of auditory training programs as rehabilitative components for those with hearing loss, research conducted with cochlear implant recipients also has led to development of other computer-based interactive auditory training programs. One reason auditory training with cochlear implants is needed is because the processing of speech patterns (i.e., spectral and temporal resolution) is different for electrical stimulation provided by the cochlear implant compared to the processing of speech patterns through acoustic hearing via hearing aids (Fu & Galvin, 2007). Although speech patterns are degraded for cochlear implant users and hearing aid users, and both groups do benefit from auditory training, the long term use of the cochlear implant device does not necessarily result in the individual learning novel stimulation patterns (Fu & Galvin, 2007). The *House Ear Institute* (*HEI*) recently launched a computer-based auditory training program called *Sound Express*™ (TigerSpeech Technology, Innovative Speech Software, 2005-2006; www.tigerspeech.com). Sound Express™ offers an adaptive speech-in-noise auditory training program with analytic and synthetic discrimination and identification tasks that can be completed in the individual's home. Within the Sound Express™ system are the testing and training programs, the *Internet-Based Speech Testing,* *Assessment, and Rehabilitation* (*i-STAR) and the Internet-Based Computer Assisted Speech Testing* (*i-CAST*). The *i*-STAR program was developed to serve as a standardized speech assessment tool for research and clinic environments and is an open-set speech recognition testing and training module, while the *i*-CAST program is designed for closed-set speech recognition testing and training. Research conducted by Fu and Galvin (2007) relative to an earlier downloadable version, the Computer Assisted Speech Testing (CAST) program provided results for cochlear implant recipients. In their study, ten adult cochlear implant recipients were recruited for training with the CAST that was loaded directly onto their home computers. Prior to beginning CAST all participants underwent two weeks of baseline training on multi-talker phoneme recognition. The level of difficulty within CAST adapts based on the individual's response. Thus, CAST allows for training levels to be set relative to each individual's ability. The participants in Fu and Galvin (2007) were trained at a moderate training difficulty level, one hour per day, five days a week for a duration of one month or longer. Tasks being trained were speech perception for monosyllabic words relative to second formant vowel and consonant contrast differences and duration difference (i.e., "said versus seed; sad versus sawed") (p. 198). Positive feedback was provided in the form of auditory and visual indications of correct versus incorrect responses throughout the training. During training, participants returned to the House Ear Institute every two weeks for retesting on multi-talker phoneme recognition performance. Results were reported by Fu and Galvin as follows; a) vowel and consonant recognition significantly improved for all participants post training (i.e., after at least one month of training), b) significant improvements were reflected in the mean vowel recognition score by 15.8%, c) mean consonant recognition scores significantly improved by 13.5%, and d) despite receiving training for consonant and vowels only, a subset of three participants also significantly improved their mean sentence recognition scores by 28.8%. All participants demonstrated significantly improved consonant and vowel recognition scores, albeit individual variability was shown relative to the overall amount of improvement and time it took to improve as training lasted for four weeks or longer. Thus, some participants showed significant improvement after training for only a few hours while others needed more time before improvements occurred. Results from this study further support previously reported evidence for the benefits of auditory training in improving speech perceptual abilities, generalization of auditory learning, and neural plasticity within the brain. These researchers indicate that “behavioral transfer of learning” and plasticity in underlying physiologic processes” occurred because some of the participants in their study demonstrated generalized improvements in performance for stimuli not directly used for training (i.e., improvement in sentence recognition) (p. 202). Furthermore, these results indicate the benefits of auditory training for individuals with severe to profound hearing loss.

Miller, Watson, Kewley-Port et al. (2008) and Miller, Watson, Kistler et al. (2008) recently introduced the *Speech Perception and Training System* (*SPATS*; Communication Disorders Technology, Inc.; www.comdistec.com). SPATS is a new auditory training program that can be used for training with hearing aid users, cochlear implant recipients, and individuals with hearing loss that do not use amplification devices. SPATS is a computer-based auditory testing and training program that uses identification tasks for analytic and synthetic speech materials in quiet and in noise (at either fixed or adaptive signal to noise ratios (SNRs)) to measure and train individual perceptual skills. For analytic training, individuals progress through four adaptive training levels in order to achieve a mastery score for each level (Miler, Watson, Kewley-Port et al., 2008; Miller, Watson, Kistler, et al., 2008). For synthetic training, a three sentence set was used to adaptively move the individual through the session while attempting to maintain a SNR between 0 and -10 dB (i.e., accuracy on three consecutive sentences would result in a reduced or more difficult SNR on the next sentence set).

In 2008, Miller, Watson, Kewley-Port et al., and Miller, Watson, Kistler, Wightman and Preminger (2008) reported results for a study using SPATS in which hearing aid and cochlear implant users were tested and trained on syllable and sentence identification in quiet and in noise. These investigators had 12 hearing aid users (i.e., eight trainees and four controls) and 16 cochlear implant users (i.e., eight trainees and eight controls) ranging in age from 26-90 participating in their study. Testing and training based on the SPATS syllable and sentence program was conducted for pre and post SNR testing. Specifically, the SPATS program has built-in testing that includes the assessment of *"Constituents in Quiet"* and *"SNR Adaptation"* to assess performance in noise (p. 4). In addition, non-SPATS pre and post testing was conducted using the *HINT* (Nilsson, Soli, & Sullivan, 1994; Maico Diagnostics, Eden Prairie, MN) in quiet and in noise (+8 dB SNR), *Central Institute for the Deaf (CID)* W-22 word lists (Hirsh, Davis, Silverman, Reynolds, Eldert, & Benson, 1952) in quiet and in noise (+8 dB SNR), and the *Connected Speech Test* (*CST*) (Cox, Alexander, & Gilmore, 1987; Hearing Aid Research Laboratory; www.memphis.edu)-(HA group only) for auditory-visual and auditory-alone conditions at a -4 dB SNR for each condition. For cochlear implant users, testing was conducted using CNC word lists (specific CNC word lists not specified) in quiet and the HINT in quiet and in noise (+10 dB). Also used in pre and post measures were selected self report questions from Gatehouse and Nobles' (2004) *Speech Spatial and Qualities of Hearing Scale (SSQ)* and a SPATS questionnaire (Miller, Watson, Kistler et al., 2008. Participants trained for six weeks (two two-hour training blocks/week) and completed between six and 12 training rotations equaling 12 to 24 hours of overall training. The control participants underwent pre testing on several non-SPATS and SPATS tests, however, did not participate in training. After pre-testing concluded, the control participants for the hearing aid and cochlear implant groups did not receive any additional exposure to the SPATS program for several weeks. Upon completion of the six week training sessions by the trainees, all participants returned to the clinic for testing on SPATS and non-SPATS materials. Although the trainees progressed through the SPATS program fairly independently, training and testing occurred under the direct supervision of the investigators at designated research laboratories (Miller, Watson, Kistler et al., 2008. The presentation level for the speech stimuli used in testing and training was 65 dB SPL. Results reported by Miller, Watson, Kistler et al. for the SPATS training revealed individual variability in training results. However, on average both hearing aid users and cochlear implant users had an average gain for constituents in quiet (i.e., syllables) of 7%, an average reduction in SNR of 7.3 dB ; and a highly significant overall average gain on speech perceptual tasks of 11% based on comparison of pre and post training measures. In addition, control participants did not demonstrate any improvement for SPATS or non-SPATS test materials. Results for the non-*SPATS* outcome measures (i.e., CID W-22 in quiet and in noise; HINT in quiet and in noise; CST-AV and CST-A) for the hearing aid users revealed an average improvement for all conditions of 8% relative to no improvements for the controls. Furthermore, the majority of the hearing aid trainees had improved sentence scores at signal to noise ratios (SNRs) ranging from -5 to -15 dB, which reflect more difficult SNRs relative to the training SNR levels of 0 to -10 dB. Interestingly, for the hearing aid users in this study, the HINT scores were “too high” (i.e., ceiling effect) and the CST auditory only at -4 dB SNR material was too difficult (i.e., floor effect) to produce significant differences in scores relative to the control group. The trainees from the hearing aid group had an overall training improvement for non-SPATS material of

10%. Furthermore, in general, training improvements observed for the hearing aid trainees was equal for all SPATS and non-SPATS materials. Results for non-SPATS measures (i.e., CNC in quiet; HINT in quiet and HINT in Noise) for the cochlear implant group revealed an overall mean gain of nine percent across all conditions. However, the biggest improvement for the cochlear implant trainees was reflected in an average improvement of 13% which occurred for the HINT sentences in quiet. For all trainees, an overall average training gain of ten percent was reported based on pre and post testing relative to the controls. When comparing the SPATS study with the LACE™ study it appears that with the exception of the results from the HINT tests for the cochlear implant group, hearing aid participants in the SPATS study and the LACE™ study had no significant change in HINT scores. However, all other results were consistent with auditory training improvements.

Summary and Rationale

Histological evidence from animal and human studies has provided empirical data reflecting the anatomical and molecular degenerative processes with aging that may contribute to deficits in speech perception. As a result of these age-related degenerative changes, deficits in peripheral auditory, central auditory and cognitive functions may ensue. Determining effective management for such deficits is even more critical given life expectancy data that indicates an increase in the elderly population.

The normal peripheral auditory system allows for the effective transfer of sound from the outer ear, to the middle ear, into the inner ear. Presbycusis or age-related sensorineural hearing loss is the third most common condition in the elderly population. Hearing sensitivity is an important consideration, as the ability to accurately perceive a signal cannot be achieved without first hearing the signal. Furthermore, the presence of even mild-to-moderate hearing loss can impact measures of central auditory function and must be taken into consideration.

Central auditory processing involves neurobiological and electrophysiological mechanisms for the perceptual processing of auditory information through the central nervous system. Central auditory processing allows for the ability to process sounds in many different ways such as sound localization and lateralization, auditory discrimination, recognition of auditory patterns, temporal processing and the processing of degraded acoustical signals. Because the flow of auditory information occurs concurrently through both bottom-up and top-down processing mechanisms, deficits in central auditory processing may further impact processing and communication abilities to include speech perception, cognition, language, and learning.

As reported throughout the literature, elderly individuals with normal cognition show deficits in selected cognitive processing areas such as working memory, attention, and processing speed. Age-related changes in these higher-order processing skills are recognized as contributing to speech perceptual/processing deficits in the elderly. Hearing loss may also negatively impact cognitive functioning, such as working memory. Hearing loss can restrict working memory as those with hearing loss appear to expend more perceptual effort on speech processing. This is because individuals with hearing loss do not have access to all components of the signal. That is, they use more bottom-up processing resources on signal identification and therefore, have fewer resources and more difficulty encoding speech into memory.

Another cognitive factor contributing to speech perceptual declines is that of age-related deficits in attention. Because the brain is limited in its’ capacity to attend to sensory inputs at a given time, processing of the intended signal may be affected. This limited capacity is further compromised in the aging brain. Empirical evidence from several different studies suggests that performance on selective attention tasks that require the suppression of distracter stimuli and divided attention tasks are negatively affected by aging. This is especially relevant when listening to speech in noise because this is a task that requires suppression of the distracting noise.

Studies of the effects of aging also indicate an overall slowing of processing speed. Although, slower processing speed does not cause a singular catastrophic loss for processing information, it can lead to a reduction in the efficiency of multiple processes. Research indicates that there are several age-related shared variables (i.e., knowledge, reasoning, memory, perceptual speed) that contribute to the overall speech perceptual processing abilities of older adults. In support of this conjecture, researchers have demonstrated age-related changes in the processing of time-compressed speech that impacts speech identification as well as cognitive processing.

One approach that can be used to assist the older adult with reducing speech perceptual deficits is through the introduction of aural rehabilitation techniques such as auditory training. Auditory training uses structured listening practice to facilitate auditory learning and improve auditory perceptual abilities. Auditory perceptual learning is accomplished by practice on a stimulus set that leads to improvement in performance for that stimulus set and which may generalize to other stimuli. Through listening practice, an individual may improve their perceptual performance for one or more auditory tasks and demonstrating auditory learning. Results from several studies of auditory training in adults indicate enhancements in neural response and behavioral perceptual abilities post auditory training for both speech and non-speech stimuli. It is reported that training based improvements in neural activity may occur from within minutes to several days, depending on the complexity of the auditory training task. These are promising results as they demonstrate the plasticity of the adult brain.

Speech perception in the elderly population may be impacted by numerous age-related changes in peripheral auditory, central auditory and/or cognitive systems. Prior research has focused on demonstrating the benefits of auditory training (i.e., syllable, word, and sentence-based materials) on selected speech identification measures. This research indicates that speech perceptual abilities in the elderly population may improve with auditory training.

A few recent studies have investigated the benefits of syllable, word and sentence-based auditory training. Of three studies investigating syllable training, two found that syllable training improves sentence identification, whereas one found no benefit. Of two studies investigating word-based auditory training, both found improved word recognition. However, only one study found additional improvements in sentence and syllable identification. Of three studies examining sentence-based auditory training, all three reported improved sentence identification, whereas only one of the three studies found an additional improvement in word recognition. Only one study examined and found cognitive improvements post training; however, that study included both auditory and cognitive training. Sentence-level auditory training may improve sentence identification and syllable identification.

The current study explored the impact of auditory and auditory-cognitive training on speech perception, selected cognitive abilities, and self reported perceptions and communication performance. One group of participants underwent sentence-based auditory training only, a second group underwent sentence-based auditory training and cognitive training, and a third group underwent a structured story listening task. In contrast to other studies, the current study used older adults who are not hearing aid users. This is the first study to explore whether a cognitive training component further enhances speech perceptual abilities, cognitive abilities, and self reported perceptions and performance above and beyond changes from auditory training only.

Another unique aspect of the current study is the use of a listening control group (i.e., short stories on CD). There is no published data to date regarding whether structured listening may serve as a control or might also result in speech perceptual and/or cognitive changes in older adults 60 to 80 years of age. This is another important consideration because one professional audiological goal is to provide auditory rehabilitation strategies that are most advantageous for older individuals with mild to moderate hearing loss. Because the average individual with hearing loss waits several years before seeking out assistance, potential changes in speech perceptual and/or cognitive abilities produced by means of an informal listening program may prove to be of benefit for those unable to participate in a formal auditory training program.

Plan of Study and Experimental Questions

The current study explores speech perceptual abilities, selected cognitive abilities and self report measures of feelings and communication performance before and after six days of formal auditory training or a listening to stories control condition. The formal auditory training program that is used is the LACE^{TM} 4.0 DVD program with and without the cognitive training sections. Within seven to ten days from the onset of training or controlled listening activities, participants again completed the test battery of speech perceptual, selected cognitive assessments (i.e., attention, working memory, processing speed), and self report measures of feelings and communication performance.

The following experimental questions were answered:

1. Following training or control activities, are there significant changes for each group on measures of speech perceptual abilities (WIN, CST, DSI, TC, DDT, & i-CAST, cognitive

processing (BTA, NR, & ARTT), and self-report of feelings, confidence, and communication performance (CPHI, SIR, & CCQ)?

2. Is there a significant correlation between performance change on speech perceptual measures (WIN, CST, DDT, & i-CAST) and the preliminary scores on selected self-report (CPHI) and cognitive measures (BTA, NR, & ARTT)?

3. Are the preliminary scores for the CPHI and CCQ self-report measures significantly correlated with one another?

4. Are the preliminary scores on the speech perceptual measures (WIN, CST, DSI, TC, DDT, & i-CAST) significantly correlated?

5. Is there a significant correlation between preliminary scores on tasks requiring rapid processing speed (TC, ARTT, & i-CAST)?

6. Is there a significant correlation between preliminary scores on tasks requiring cognitive processing (DDT, BTA, & NR)?

CHAPTER II

METHOD

Participants

Thirty five older adults participated. The study participants were adults 60 to 80 years of age who are native speakers of English and have hearing difficulties but have never worn hearing aids (i.e., other than during an in-office trial). In addition, Institutional Review Board (IRB) approval was sought and granted for this study. Prior to any testing, the University and Medical Center Institutional Review Board Consent Document was reviewed and signed. This form is presented in Appendix A. Participants were required to have access to a computer with loudspeakers and a DVD player, and were recruited from the research participant pool at East Carolina University, via brief face-to-face announcements or flyers posted at churches, local medical facilities, community centers local clubs and organizations (Appendix B), as well as via newspaper advertisements (Appendix C). All participants were from Greenville, North Carolina or surrounding counties.

Prior to scheduling for a study qualification and evaluation appointment, potential participants were asked to confirm that they: 1) are not currently being treated for any ear related problems; 2) have hearing difficulties but are not wearing hearing aids and have not worn hearing aids in the past; 3) asked at what age they first noticed their hearing difficulties; 4) if they have a family history of hearing loss; 5) have no history of ear surgery within the past 10 years; and 6) have a computer with loudspeakers and/or a DVD player (Appendix D). If they met the above criteria, the individual was scheduled for a study qualification and evaluation appointment.

Study Qualification Measures

As study participants are not hearing aid users they were offered a Pocket Talker amplification device as a means for more effectively hearing the researcher in face to face communication. Prior to any testing, the informed consent was reviewed and signed. For inclusion in the study, participants were required to have normal otoscopy, tympanometry, acoustic reflex thresholds, symmetrical mild-moderate sensorineural hearing loss, word recognition related to degree of hearing loss, and no more than mild cognitive impairment as indicated below.

Otoscopy was performed to rule out auditory pathology associated with the external auditory canal or tympanic membrane. Otoscopy was performed with a hand-held Welch Allyn otoscope in order to visually inspect the external auditory canal for the presence of structural deficits, cerumen, foreign body, otitis externa, ear canal debris such as: ear drainage, blood or secretion and visualization of tympanic membrane for perforation (ASHA, 2005a). Observations of most of these conditions would lead to a medical referral. If excessive cerumen was observed (i.e., 80% blockage with no visualization of the eardrum) (Ballanchanda, 1995), the individual was advised of various options for removal such as at-home procedures, or referral to a physician or audiologist. Participants with any active (i.e., non-resolved) conditions, as indicated above, were not included in the study.

To rule out potential middle ear pathologies, tympanograms were measured for both ears. Tympanometry were performed using a Grason-Stadler TympStar Middle Ear Analyzer system calibrated according to ANSI 2007 standards. Testing was conducted using a low frequency 226 Hz probe tone, a positive-to-negative (i.e., +200 to – 400 daPa) pressure sweep, and a standard pump speed of 600/200 decaPascals per second (daPa/s). Tympanometric measures of peak static acoustic admittance (Ytm), equivalent ear canal volume (Vea), and tympanometric width

(TW) were evaluated. Normative values of 0.2 – 1.9 mmho for Y_{TM}, 0.8 – 2.2 cm3 for Vea, and 25 – 145 daPa for TW (Wiley, Cruickshanks, Nondahl, et al., 1996) were used to define normal middle ear function. These normative data were selected because it was based on a normative sample of adults ranging in age from 48-92. Any participant with values outside these ranges was excluded from the study.

Contralateral acoustic reflex thresholds (ARTs) were measured at peak static acoustic admittance pressure values obtained from tympanometry via the same Grason-Stadler TympStar Middle Ear Analyzer system to contraindicate retrocochlear involvement. Acoustic reflex thresholds were obtained with 500 Hz, 1000 Hz, and 2000 Hz tones for contralateral stimulation. The initial tonal presentation was 85 dB HL. If an observable reflex was noted (i.e., stimulus time-locked decrease of at least .2 ml), then the tonal stimulus was set to 70 dB HL and increased in 5 dB steps to determine the lowest stimulus level needed to elicit a response. If a response was not observed at 85 dB HL, then the stimulus level was raised in 5 dB HL steps until either the maximum stimulus level was reached or loudness discomfort occurs. The ART was defined as the lowest level a measurable response was observed on two stimulus presentations (i.e., a repeatable response). If ARTs were above the 90th percentile for two or more frequencies in one or both ears in the presence of normal hearing or sensorineural hearing loss (Gelfand et al., 1990), then that finding was considered a sign of possible retro-cochlear involvement, excluding the individual from study participation. These procedures, descriptions, and normative data were based on the 90th percentile range as determined by Gelfand et al. (1990).

All participants underwent pure tone air and bone conduction threshold testing with procedures based on the “Guidelines for Manual Pure-Tone Threshold Audiometry” (ASHA 2005b). All testing was conducted in a double-walled sound attenuated booth. Manual pure-tone audiometry was performed using a Grason-Stadler GSI 61 audiometer calibrated to American National Standards Institute (ANSI) 2004 standards. Air conduction thresholds were obtained using pulsed-tone stimuli for frequencies of 250, 500, 1000, 2000, 3000, 4000 and 6000 Hz with ER 3A insert earphones. In order to evaluate pure tone threshold reliability, the air conduction threshold at 1000 Hz was re-evaluated in both ears and were required to be within 5 dB of the initial measure (i.e., as recommended by ASHA, 2005b). Pure-tone bone conduction threshold testing was conducted using a B-71 bone conduction vibrator. The bone vibrator was first placed on the mastoid of the ear with the poorest 3-frequency pure tone average for air conduction thresholds. “Best” bone conduction thresholds were measured using pulsed tones at 500, 1000, 2000, and 4000 Hz. If the best bone conduction threshold at any of these frequencies was more than 10 dB better than either the right or left air conduction threshold at that frequency, then contralateral masking was used to obtain a masked bone conduction threshold. For study inclusion, participants were required to have bilateral mild-to-moderate symmetrical sensorineural hearing loss characterized by the following:

1. air conduction thresholds were recorded on a University approved audiogram (Appendix E). Air conduction thresholds were measured from 250-6000 Hz; however, inclusionary criteria for air conduction thresholds ranged from 25 dB HL up to 60 dB HL from1000 through 4000 Hz (Souza, 2009) with no exclusionary criteria for thresholds at 250, 500, or 6000 Hz. Initial data collection based on these audiometric criteria; however, resulted in the exclusion of many potential participants. A decision was made to slightly alter the audiometric criteria to allow for the inclusion of more participants. The altered inclusionary criteria allowed for pure tone averages for thresholds at 1000, 2000 and

4000 Hz to range from 20 dB HL up to 60 dB HL (ASHA, 2005b, Jerger & Jordan, 1980);

2. no more than 15 dB HL interaural difference in air conduction thresholds from 250-4000 Hz in order to rule out asymmetrical hearing loss (Harris et al., 2009; Tun et al., 2002);
3. no more than one air-bone gap greater than 10 dB from 500-4000 Hz per ear (Margolis, 2008).

Word recognition testing in quiet was conducted for each ear using a different 50-item Northwestern University NU-No. 6 word list recorded by a female speaker from the Speech Identification and Recognition Material Department of Veteran Affairs Disk 2.0 (1998). The first 25 words from List 3A were presented to the right ear and the second 25 words from List 3A were presented to the left ear. Participants were seated comfortably in a double-walled sound attenuated booth. Word recognition test lists were presented via a compact-disc player routed through a Grason-Stadler GSI 61 audiometer calibrated to ANSI 2004 standards. Prior to test list presentation, the calibration tone on track 1 of the CD was set on both channels of the audiometer via the VU meter to establish a leveled peak setting of the calibration tone at 0VU (Wilson and Margolis, 1983, p. 98). Once the calibration is completed, the material was routed to the ER-3A insert earphones for testing. The presentation level was set at 40 dB sensation level (SL) re: the standard three-frequency pure tone average (500, 1000 and 2000 Hz) and a set of up to three words were presented from NU-6 list 2A (i.e., list not used in testing) to insure that this level was not uncomfortably loud. If the 40 dB sensation level was uncomfortably loud, then the SL was decreased in 5 dB steps with up to three words at each level until discomfort was no longer reported. The right ear was arbitrarily chosen as the initial test ear for each participant. Each participant was instructed that they will hear the carrier phrase, “Say the word

______". The participants were instructed to repeat only the word at the end of the phrase and to guess at the word if necessary. Scores were calculated per ear and were based on the percentage of correct words. The NU-6 word test materials were chosen because they were reported as being the most commonly used clinical word recognition test material (Wilson & Strouse, 2002) and because subsequent NU-6 words were used as the material in the Words-in-Noise (WIN) test (Wilson, 2003; Wilson & Burks, 2005) and Time-compressed speech test (Kurdziel, Rintelmann, & Beasley, 1975; Wilson, Preece, Salamon, Sperry, & Bornstein, 1994). In order to qualify for the study, word recognition scores for both ears were required to be within the 95% confidence limits reported by Dubno et al. (1995). According to Dubno et al., if a participant's word recognition score at a single presentation level was not within limits, then other levels may be presented; those investigators used levels up to 100 dB HL. In the current study, if an initial word recognition score was not within expected limits for the degree of hearing loss, then the presentation level were raised 10 dB above the initial presentation level with another 25-item word list (unless loudness discomfort occurred and then a level 5 dB higher than the initial level was used) with no presentation levels for any participants exceeding 100 dB HL.

For study inclusion, participants were administered a cognitive screening to rule out moderate or severe cognitive impairment. Each participant was provided a Pocket Talker amplifier set at a comfortable listening level for the administration of this test. The Mini Mental State Exam (Folstein, Folstein, & McHugh, 1975) was administered and only those receiving scores of 18 or above were included in the study (www.medicine.uiowa.edu/igec/tools/cognitive/MMSE.pdf). The MMSE was described as a 30 item paper-and-pencil screening tool which contains five cognitive categories (i.e., orientation, registration, attention and calculation, recall, language) and six sub-categories under the language category of: repetition, three-stage command, reading, writing and copying (Folstein, Folstein & McHugh, 1975). In the current study, each participant was seated comfortably in a quiet test room with adequate lighting for the administration of the cognitive screening. The screening material was verbally presented to each participant by the principal investigator. Verbal and written responses for each participant were scored based on the number of items correct.

Outcome Test Materials and Stimuli

Pre training and post training outcome testing occurred over a two hour time period with participants offered two ten minute breaks during each session. With the exception of one cognitive test, all speech perceptual and cognitive testing were conducted with participants seated comfortably in a double-walled sound attenuated booth. Administration of the Auditory Reaction Time Test (ARTT) (SuperLab Pro 4.08; Cedrus Corporation, 2008) was conducted in a quiet research laboratory with the principal investigator seated alongside the participant. Administration of the paper-and-pencil self reports were conducted in a quiet research laboratory with the principal investigator seated alongside the participant in order to visually and orally review each questionnaire item. In addition, administration of all paper-pencil self-reports included the use of a Pocket Talker amplifier worn by the participant. The presentation order for all tests was randomized via an internet-based random numbers generator program (http://www.random.org/sequences/?min=1&max=11&col=1&format=html&rnd=new). For presentation of all monaural test stimuli, the ear with the better standard three-frequency pure tone average (i.e., thresholds at 1000, 2000, and 2000 Hz) was used. Although Humes (1996) and McCoy et al. (2005) recommend the use of the high frequency PTA (i.e., 500, 1000 and 400 Hz) as being a better predictor of speech perceptual performance, the majority of the research protocols followed in the current study used a standard three-frequency PTA. Therefore, the standard three-frequency PTA were used for the current study. In situations where both ears have the same standard three-frequency PTA, the right ear was used for testing.

Speech Perception, Cognitive, and Self-Report Measures

Testing for each participant consisted of six speech perceptual assessments including the Words-in-Noise (WIN) Test (Wilson & Burks, 2005), the Connected Speech Test (CST) (Cox et al., 1988), the Dichotic Sentence Identification (DSI) Test (Fifer et al., 1983), the Time-Compressed (TC) Speech Test (Wilson, Preece, Salamon, Sperry, & Bornstein, 1994) the Dichotic Digits Triplets Test (Strouse & Wilson, 1999; Strouse Wilson & Brush, 2000a; Strouse Wilson & Brush, 2000b) to assess divided attention (Free-Recall condition) and auditory working memory (Directed-Recall condition) (Cameron & Dillon, 2005), and the Internet-Based Computer Assisted Training (i-CAST) Test to assess both processing speed and syllable (i.e., consonant) identification (Fu & Galvin, 2005; 2007; Tiger Speech Technology, v 5, 2006); three cognitive assessments, including the Brief Test of Attention (BTA) to assess selective attention, (Schretlen, Bobholz & Brandt, 1996; Schretlen, 2009), the Numbers Reversed (NR) Test (Mather & Woodcock, 2001) to assess auditory working memory, and Auditory Choice Reaction Time Test (AR) (SuperLab Pro, 4.0, Cedrus Corporation, 2008) to assess processing speed; and three self report assessments, including the Communication Profile for the Hearing Impaired (CPHI) to assess feelings and communication performance (Erdman & Demorest, 1998), the Speech Intelligibility Rating (SIR) Test to assess speech perception in noise communication performance (Cox & McDaniel, 1989), and the Communication Confidence Profile (CCP) to assess confidence in communication (Sweetow & Henderson Sabes, 2010). The test material presentation levels are based on levels recommended by the researcher(s) who developed the tests. If the presentation level for any test was deemed uncomfortably loud by the participant, the level was reduced in 5 dB steps until the discomfort is resolved, as previously described. This protocol was maintained for all tests.

Calibration and Instrumentation for Speech Perceptual Testing

Three experimental tests (BTA, NRT, ART) did not offer calibration tones to allow for calibrated presentation levels. According to the American National Standards Institute (ANSI) S3.6 (2004), calibration tones for recorded speech materials should be set to the average dB RMS SPL corresponding to the entire set of speech stimuli. This procedure was followed in order to develop calibration tones for theses materials.

Calibration tones were developed for the Brief Test of Attention (BTA) (Schretlen, 2009), the Numbers Reversed Test (Mather & Woodcock, 2001), and the Auditory Reaction Time Test (SuperLab Pro version 4.08; Cedrus Corporation, 2008). A calibration tone CD was produced for The Brief Test of Attention (BTA) (Schretlen, 2009) and The Numbers Reversed (NR) Test (Mather & Woodcock, 2001) to allow for calibration of these two psychological test materials. The SpectraPro software (version 3.32.18d) (Sound Technology, Inc.) on a Dell laptop computer was connected via cable to a JVC Compact Disc player. The average dB RMS SPL was determined for all of the recorded words on each psychological test. That average dB RMS SPL for each test was then entered into the Cool Edits 96 software program (Syntrillium Software Corporation) for the creation of a calibration tone that “matched” that average dB RMS SPL. That calibration tone was saved and recorded onto a CD using the Primo DVD (version 2.1) software program (Primera Technology, Inc.).

Using this same technique, two additional calibration tones were created for the words RIGHT and LEFT for the Auditory Reaction Time Test (SuperLab Pro version 4.08; Cedrus

Corporation) using SpectraPro and Cool Edits 96 software programs. These calibration tones were saved and uploaded directly into the SuperLab Pro experiment software program.

Prior to the presentation of all auditory testing, the calibration tone was calibrated through both channels of the audiometer via the VU meter to establish a leveled peak setting of the calibration tone at 0VU (Wilson, and Margolis, 1983). Daily calibration of the GSI Tympstar equipment was conducted using a 2cc couple cavity.

Speech perceptual measures.

Words-In-Noise (WIN) Test

The Words in noise (WIN) test was used to assess word recognition abilities in noise. It was specifically designed for use with adults who have pure tone averages less than 60 dB HL. The WIN test consists of seventy words from the VA *and Speech Materials for Auditory Perceptual Assessment Disk 2.0* (1998) NU-6 recordings that were divided into two half lists of 35 words per list that are presented at seven signal-to-babble (S/B) ratios from +24 to 0 dB S/B. The S/B ratios were established by holding the noise level constant at 60 dB HL while the level of the words was decreased in 4 dB steps from 84 dB HL to 60 dB HL. Five words are presented per S/B level beginning with the +24 S/B ratio with word sets presented in 4 dB decrements down until the stopping criteria was met or the 0 S/B ratio was reached. The stopping criteria for the WIN test was used in that missing all words at any one S/B level results in the cessation of testing (Wilson & Burks, 2005; Wilson & McArdle, 2007). The WIN test was administered in a double-walled sound-attenuated test suite using the recommended protocol from Wilson and Burks (2005). For pre-training assessment, WIN List 1 from the Department of Veterans Affairs *Speech Recognition and Identification Materials, Disk 4.*0 (no date) was presented via ER-3A insert earphones with the test materials directed to the better ear (i.e., re: the standard three-frequency pure tone average) or right ear if both are the same at a presentation level of 80 dB HL (Wilson & Burks, 2005). WIN List 2, an equivalent test list, was used for post testing. The participant was instructed to listen for each word presented and repeat each word or offer a guess when uncertain. The score for the test was represented by a raw score converted into a percent correct score per ear determined by the number of correct items out of the total number of points for the test (i.e., 30 out of 35). The WIN test was selected for use in this study because: 1) it has a means of assessing word recognition in noise that uses the NU-6 recordings (i.e., most commonly used clinical material), 2) it has been found to have intra and inter session test-re-test reliability for individuals with mild-to-moderate sensorineural hearing loss (Wilson & McArdle, 2007), and 3) it has been highly correlated with scores from the longer Quick-SIN test (Wilson, McArdle, & Smith, 2007). The WIN material was chosen instead of the Quick-SIN material because the Quick SIN was the testing material used throughout LACE$^{\text{TM}}$ 4.0 (LACE$^{\text{TM}}$ 4.0 Training Manual, 2009).

Connected Speech Test (CST)

The audio only portion of the Connected Speech Test Version 2 (CSTv2) (Cox, Alexander, Gilmore, & Pusakolich, 1988) will be used to assess speech recognition of everyday sentence material in noise. The test will be administered in a double-walled sound-attenuated test suite using the protocol recommended by Cox et al. (1988). This test uses sets of topic-related sentences nine to ten words in length. The test material contains 48 sets of topically related sentences with each sentence set containing 25 key words (Cox et al., 1987; CST Manual, 2003). Cox et al. established equivalence for 24 pairs of sentence sets. For testing, two sentence sets (i.e., 40 sentences) were used to generate a score. For the current study, on the pre-training measure, lists 1 and 2 will be used and for post-training lists 3 and 4 will be used. All sentences were presented to the participant's ear via ER-3A insert earphones at a presentation level of 50 + (PTA/2) (a level approximating that recommended by Cox et al. Stimuli were routed to participants' one sentence at a time through a two-channel GSI 61 audiometer with the female talker in the left channel and the speech babble in the right channel and both mixed when presented through the earphone (CST Manual Version 1.0, 2003). The participant was verbally advised of the passage topic prior to administration of each passage. The participant was instructed that the speech and multi-talker babble was going to be presented together to the right ear and that following the presentation of each sentence, the speech and babble material would be stopped so that the participant could respond by verbally repeating the entire sentence. If any word or words within the sentence was missed, the participant was encouraged to guess at the word(s) (CST Manual, 2003). The CST stimuli were produced from the *Hearing Aid Research Laboratory (HARL) compact disk*. The score for the test were represented by a raw score determined by the number of correct items out of the total number of points for the test (i.e., 30 out of 100). Prior to testing, it was necessary to determine the speech-to-babble ratio to be used during testing. In the current study, each participant was presented one sentence set (i.e., 20 sentences), at ratios of +4 S/B; +2 S/B and at 0 S/B respectively. The S/B yielding a score closest to 70% will be selected for use in pre and post training outcome assessment. When used with hearing aid patients, the presentation of four or more passages at all three S/B levels was recommended in order to approximate the 70% level. However, in the current study's protocol, if 70% or lower was established at the first or second S/B level (i.e., +4 or +2), then no further S/B adjustments were presented and the level in which 70% or greater was achieved was used for the testing. Presentation of the two test sentence sets follows.

Dichotic Sentence Identification (DSI)

The Dichotic Sentence Identification test (Fifer, Jerger, Berlin, Tobey & Campbell, 1983) was used to assess binaural integration, possibly representing the manner in which the central auditory nervous system (CANS) processes information from multiple sources. In the current study, the test was administered in a double-walled sound-attenuated test suite using the protocol recommended by Fifer et al. (1983). The DSI was described as being a modified version of the Synthetic Sentence Identification (SSI) test and uses the same thirty pairs of SSI nonsense sentences, except there were a total of six sentences to choose from instead of ten sentences (i.e., "Go change your car color is red") (Fifer et al., 1983). The DSI test stimuli used were from the *AUDiTec of St. Louis*™ disk. The test material was presented dichotically and routed to the participant via a two channel audiometer with channel one set on external A for the right ear and channel two set on external B for the left ear and delivered through ER-3A insert earphones at a presentation level of 50 dB SL re: PTA at 500, 1000 and 2000 Hz in each ear (Bellis, 2003; Fifer et al., 1983). Randomization list F was used for practice and Randomization List G was used for pre and post training testing. Prior to the testing, participants received 30 practice items from the *AUDiTec of St. Louis*™ disk consisting of five dichotic sentence pairs presented monaurally to each ear and 20 sentences presented dichotically. The participant was provided with a printed list displaying the six sentences from the test material and a response form. Participants were instructed to listen for the presentation of the two sentences and to write the corresponding numbers of the sentences they heard onto the response form. The score for the test was represented by a raw score determined by the number of correct items out of the total number of points for the test for each ear (i.e., 30 out of 35). The rationale for use of the DSI material was that it has been reported as being an auditory processing measure that can be used with individuals who have cognitive impairment (Gates, Anderson, Feeney, McCurry & Larson, 2008; Gates, Feeney & Myers, 2008; Strouse, Hall & Berger, 1995) and the DSI test material were not affected by hearing loss up to 50 dB HL (Bellis, 2003; Fifer, Jerger, Berlin, Tobey & Cambell, 1983; Gates, Anderson, Feeney et al, 2008).

Time-Compressed Speech (TC)

Sixty-five percent (65%) time-compressed words in which a portion of the speech waveform was shortened by digital processing was used in order to produce an effect which simulates listening to speeded speech. Alterations in time-compressed speech represent faster speech; however, by shortening the waveform, the resulting speeded speech rate does not change the "power spectrum" (i.e., pitch of the speaker's voice) of the material (Wilson, Preece, Salamon, Sperry, & Bornstein, 1994). Because the material has not been associated with temporal processing, time-compressed speech can be used to evaluate processing speed (Gordon-Salant & Fitzgibbons, 2001). In this study, the 65% time-compressed speech materials were used to assess processing speed. The test was administered in a double-walled sound-attenuated test suite using the protocol recommended by Wilson et al., 1994. The time-compressed speech test stimuli used was NU-6 words from the *Tonal and Speech Materials for Auditory Perceptual Assessment Disk 2.0* (1998). The test material were routed to the participants' better ear (i.e., as indicated by the high frequency pure tone average or right ear if both were equal) via a two channel audiometer with channel one set on external B. Prior to the testing, participants received 25 practice items from the 45% Time-Compressed speech material from the *Tonal and Speech Materials for Auditory Perceptual Assessment Disk 2.0* (1998). The purpose of the practice was to familiarize the participant with the task and speeded speech material. For testing, a fifty-word NU-6 word list (female speaker) was presented monaurally through an ER-3A insert earphone, at a presentation level of 40 dB SL re: the standard three-frequency pure tone average (500, 1000 and 2000 Hz). The participant was instructed to respond by verbally repeating each word heard. The score for the test was represented by a raw score determined by the number of correct items out of the total number of points for the test (i.e., 30 out of 50). Sixty-five percent time compression was selected in order to avoid ceiling or floor effects on this test (Kurdziel et al., 1975; Wilson, et al., 1994) and because 65% time-compressed speech was the closest rate to the time-compressed ratio of 85% used in the LACE 4.0 DVD training program (Sweetow & Henderson Sabes, 2006).

Dichotic Digits Triplets

The Dichotic Digits Triplets test was used to assess auditory divided attention and auditory working memory (Cameron & Dillon, 2005; Stouse & Wilson, 1999; Strouse, Wilson & Brush, 2000b). The test was administered in a double-walled sound-attenuated test suite using the protocol recommended by Strouse and Wilson (1999) and Strouse, Wilson and Brush (2000b). The Dichotic Digits Triplets practice and test stimuli used for the free-recall were from the *Tonal and Speech Materials For Auditory Perceptual Assessment Disk 2.0* (1998). The Dichotic Digits Triplets practice and test stimuli used for the directed-recall conditions were from research disks provided by Dr. Richard Wilson of the Department of Veterans Affairs in Mountain Home, TN. The Dichotic Digits Triplets stimuli include 25 practice items and 25 test pairs of three digits for the free-recall condition and 18 practice items and 36 test pairs of three digits for the directed-recall condition. Both conditions use numbers 1-10 (not including 7) which were presented simultaneously to each ear. The practice items consist of five dichotic triplets for each condition so that participants could be familiarized with each condition. For the free-recall condition, participants were instructed that they would hear three different digits in each ear and their task was to verbally repeat all six digits they hear in any order. In this study, for the "post-cued" condition, participants were instructed to verbally repeat the digits from the cued ear only (i.e., participant hears all six digits, and only repeats the digits from the ear cued) (Strouse, Wilson, & Brush, 2000b). The test materials were routed to the participant via a two channel audiometer with channel one set on external A for the right ear and channel two set on external B for the left ear and delivered through ER-3A insert earphones at a presentation level of 70 dB HL (Strouse & Wilson, 1999; Strouse, Wilson, & Brush, 2000b). The score for the test was represented by a raw score converted into a percent correct score per ear determined by the number of correct items out of the total number of points for the test for each ear (i.e., 30 out of 75). The DDT materials were selected for use because 1) most listeners are familiar with this type of material, 2) because cochlear sensitivity does not affect performance, and 3) digits have been shown to have a "high inter-test reliability" for young adults and elderly listeners (Strouse & Wilson, 1999, p. 558). These free-recall and directed-recall conditions were chosen because research indicates that these conditions are more taxing on ones' memory, attention, and speed of processing as well as being more difficult tasks (Strouse & Wilson, 1999; Strouse, Wilson & Brush, 2000b).

Internet-Based Computer Assisted Speech Training (i-CAST)

The *i-CAST* was used to assess consonant syllable identification in speech-shaped noise at + 10 dB SNR (Fu & Galvin, 2007; www.tigerspeech.com). The i-CAST program uses 20 of the 24 American English speech sounds (except, /h/, /ŋ/, /3/ and /Θ/) as the stimuli. Two-hundred tokens from ten talkers (i.e., five male and five female) were presented in a vowel-consonant-vowel (i.e., aCa) format to each participant via a Dell desktop computer connected to a MAICO 42 (MA 42) portable audiometer (MAICO, 2010). Prior to testing the 65 dB SPL calibration tone from within the i-CAST software program was calibrated through both channels of the portable audiometer via the VU meter to establish a leveled peak setting of the calibration tone at 0VU (Wilson, & Margolis, 1983). Stimuli were delivered binaurally to the participant through a two channel audiometer via the MA 42 TDH 39 headphones at a presentation level approximately 40 dB sensation level (SL) re: the three-frequency pure tone average (500, 1000 and 2000 Hz)(i.e., a loud but not uncomfortable level) (Hawkins, Walden, Montgomery, & Prosek, 1987). The test was administered in a quiet research lab with the principal investigator seated within the laboratory. Each participant was provided a practice session in quiet with the 20 speech tokens to familiarize them to the material. Following the practice session, the 200 token testing in speech-shaped noise began. The participant was instructed to listen to the presentation of the stimuli and to select the stimuli they heard displayed on a computer screen by using the mouse. The participant was instructed to respond to each token as quickly as possible. Upon completion of the testing, the participants' scores were saved to the computer for later analysis. The presentations of the 200 token stimuli were randomized between participants. The score for the test was represented by a raw score determined by the number of correct items out of the total number of points for the test (i.e., 30 out of 200). The i-CAST testing also yields consonant scores that are displayed in a "confusion matrix" which indicates: 1) the type of auditory perceptual sound errors the individual made, 2) calculated processing speed and accuracy (i.e., number correct) of responses and 3) the errors that were made before and after auditory training. The i-CAST allows for the assessment of phonetic/analytic level listening abilities in noise.

Cognitive test measures.

Brief Test of Attention (BTA)

The BTA (Schretlen, Bobholtz & Brandt, 1996) was used to assess auditory selective attention. This test has normative data for individuals up to 82 years of age who were screened to rule out dementia, severe psychiatric disorders, and current substance dependence. No mention was made as to screening for hearing loss in the normative sample, but the test developers suggest that it only be administered to those who are able to distinguish between spoken numbers and letters of the alphabet. The test has high internal consistency (α =.90) with good internal consistency for Forms L and Form N (α =.82 and .81, respectively). The test material has good test-re-test reliability in the elderly population (r=.70) (Schretlen, 2009). The BTA was administered in a double-walled sound attenuated test suite using the protocol recommended by Schretlen (2009). The BTA consists of two forms (L and N). On each form, there are strings of letters and numbers that range in length from four to 18 items. Each form was presented sequentially. On form L, the participant was asked to count the number of letters heard in an item sequence and verbally state that count at the end of the sequence. On form N, the participant was asked to count the numbers in the item sequence and verbally state that count at the end of the sequence (Schretlen, 2009). The order of presentation of the BTA forms was randomized across participants. The BTA stimuli were presented from the Psychological Assessment Resources, Inc. disk routed through a two channel GSI clinical audiometer and were binaurally presented via ER-3A insert earphones at 40 dB sensation level (SL) re: the standard three-frequency pure tone average (500, 1000 and 2000 Hz) (i.e., a loud but not uncomfortable level). The score for the test was represented by a total raw score for both sub-tests determined by the number of correct items out of the total number of points for the both sub-tests (i.e., 10 out of 20). The rationale for using this test was that the material presented was easy and only required the participant to attend to one stimulus.

Numbers Reversed

The Numbers Reversed (NR) test (Mather & Woodcock, 2001; Schrank, McGrew, & Woodcock, 2001; Riverside Publishing, 2002) was used to assess auditory short-term working memory. This test material was presented from the *Woodcock-Johnson III Test of Cognitive Abilities (WJ-III COG)*, standard test battery (Mather & Woodcock, 2001). The premise of this test was that the individual holds information in short-term memory, while performing a manipulation task on the material (i.e. listen to numbers presented and repeat the numbers in reverse order). The test was administered in a double-walled sound attenuated test suite using the protocol recommended by Mather and Woodcock (2001). The Numbers Reversed test consists of 30 number strings ranging in length from two to eight items. Testing begins at Sample Item C as suggested in the test book as a reasonable starting point for older adults. The participants were instructed to listen to each number string and verbally repeat the numbers in reverse order (i.e., 9-3-6-1 should be repeated as 1-6-3-9). The test was presented from track seven of the Woodcock-Johnson III Tests of Cognitive Abilities and Diagnostic Supplement disk (Riverside Publishing, 2002) routed through a GSI clinical audiometer binaurally to ER-3A insert earphones at 40 dB sensation level (SL) re: the standard three-frequency pure tone average (500, 1000 and 2000 Hz) (i.e., "a comfortably loud level") (Mather & Woodcock, 2001, p. 55). If a participant did not meet basal performance requirements then the preceding block was presented and testing continued with use of preceding blocks until a basal was established. Testing continued until the participant missed three highest numbered items in a block or completed the test. Each sequence was scored as correct (1 point) or incorrect (0 points) and the total points represent the score on the test (i.e., 30 out of 30). The Numbers Reversed test was used because the test directly assesses auditory working memory. The test has been standardized on a large sample of individuals (N= 8,818) that was representative of the US population. The standardized scores were obtained from individuals aging from 2 to 90. The test has a median reliability score for adults of .87 (Schrank, et al., 2001).

Auditory Choice Reaction Time

Auditory choice reaction time testing (ARTT) was used to assess processing speed. The participant was seated in a well lighted, quiet research laboratory in front of a Dell 15 inch computer monitor during stimulus presentation. The stimuli consist of auditory presentations of the words RIGHT and LEFT generated from a soundwave file using the SuperLab software program (Cedrus Corporation, version 4.08). The auditory stimuli were routed through a Dell desktop computer to a MAICO 42 (MA 42) portable audiometer (MAICO, 2010). Presentation of the stimuli was via the MA 42 TDH 39 headphones for delivery to the participant at approximately 40 dB SL (re: the standard three-frequency pure tone average). All reaction time measures and randomization of stimuli are built into the stimulus presentation protocol based on programming through the SuperLab software program. Prior to data collection for this test, ten practice pairs of the words RIGHT and LEFT were presented to familiarize the participant with the task and to ensure that the presentation level was loud but comfortable. Following the practice trials, stimulus trials consist of 30 pairs of the words RIGHT and LEFT randomly presented to the participant. The participant was instructed to respond as quickly as possible by pressing either the right mouse button or the left mouse button corresponding to the presentation of RIGHT/LEFT, respectively. Reaction time, raw score and correct percent scores were automatically calculated via the SuperLab software program and stored in the program on a password protected computer. The score for the test was represented by a raw score determined by the number of correct items out of the total number of points for the test (i.e., 10 out of 30).

Rationale for using this test was 1) the availability of the test and 2) cognitive research has supported the use of this test with individuals with mild-to-severe hearing loss (Vaughn et al., 2008).

Social validation measures.

Communication Profile for the Hearing Impaired (CPHI)

Selected sections from the Communication Profile for the Hearing Impaired (CPHI) (Demorest & Erdman, 1987) was used as a self-assessment tool to subjectively evaluate communication areas related to each participant's perception of communication abilities. The entire CPHI consists of a "paper and pencil" form that has 145 items within four communication areas: Communication Performance (CP), Communication Environment (CE), Communication Strategy (CS) and Personal Adjustment (PA). Scores can be determined for 22 scales plus 3 "importance ratings" (based on social, work, and home environments) (Erdman, 2006, p.3). A total of 48 selected items from each of the following scales were used in this study: Average (Communication Performance); Adverse (Communication Performance), Verbal Strategies; Non-Verbal Strategies; Discouragement, and Stress. The CPHI requires use of a five point response scale either based on a frequency continuum (i.e., rarely, sometimes, half the time, often and almost always) or on an agree-disagree continuum (i.e., strongly disagree, disagree, uncertain, agree, strongly agree) (Erdman, 2006). The participant was provided a Pocket Talker amplifier set at a designated comfortable listening level for pre-and-post training assessment. The participant was seated in a quiet room alongside the researcher who visually and orally reviewed each item prior to requesting the participant's item rating. The principal investigator manually recorded all responses on the written questionnaire form. Responses from the five-point scale were manually entered by the principal investigator into a CPHI software program that was downloaded onto a password protected computer. Scores for each scale were automatically calculated via the CPHI software program. The score for the test was represented by a total raw score for each sub-test determined by the number of correct items out of the total number of points for each sub-test (i.e., 3 out of 5). The CPHI was selected for use because it has normative data from a multicenter large sample size (1008) of hearing impaired individuals. The scale items provide normative data for several listening situations that were reported as being difficult for individuals with hearing loss (Erdman & Demorest, 1998). CPHI scores correlate with other well-known self report questionnaires such as the *Satisfaction with Amplification in Daily Life (SADL)* (Cox & Alexander, 1999) and *Glasgow Hearing Aid Benefit Profile (GHABP)* (Gatehouse, 1999; Kricos & Holmes, 1996).

Speech Intelligibility Rating (SIR) Test

The SIR test (Cox & McDaniel, 1989) was used as a subjective measure to assess speech intelligibility of sentences in noise. The test was administered in a double-walled sound attenuated test suite using the protocol recommended by Cox and McDaniel (1989). This test uses topic-based sentences to create 20 connected speech test passages of ten sentences apiece. The SIR was used to establish a listener's rating as to the percentage of words s/he believes were accurately perceived (Cox & McDaniel, 1989; CST Manual, 2003). The SIR stimuli were presented from the *Hearing Aid Research Laboratory (HARL) compact disk*. Initial presentation of the material consists of a set-up passage in order to obtain a SBR rating score. The listener was offered a rating scale and asked to offer an intelligibility rating (i.e., percent of words understood) after 20 seconds of sentence materials. The intelligibility rating scale ranges from 0 – 100 with ratings at five point increments (Cox et al., 1988). The set-up passage was presented for 20 seconds in order to establish the individual's initial subjective rating for that 20 seconds of material. Following the initial 20 seconds of material, another 20 seconds of the material was presented at a level based on the subject's rating. If a rating greater than 8 was offered then the babble was raised 5 dB and if the rating was lower than 7 the babble was decreased 5 dB. This process continued for subsequent 20 second increments in order to obtain a set-up passage rating of 7-8. Once the set-up passage rating of 7-8 had been established, four test passages with the established speech babble were presented to the right ear through ER-3A insert earphones via a two-channel audiometer (Cox & McDaniel, 1989; CST Manual Version 1.0, 2003). For pre and post training assessment, passage items one to four (Tracks, 3-6) were used. The passage stimuli were presented monaurally at a fixed level of 65 dB SPL (re: calibration noise in a 6cm3 coupler (i.e., 0 dB SBR) with the level of the babble fixed based on the level obtained from the set-up passages. Initial testing using the fixed level of 65 dB SPL on a select number of participants was found to be too low in intensity to sort out the primary speaker from the babble, such that they were not able to make the intelligibility judgment. Therefore, the presentation level was delivered to the participant at 40 dB SL (re: standard three-frequency pure tone average). The participant was instructed to listen to the passages, and following the presentation of each passage, they were to rate the intelligibility of the passage based on the rating scale from 0-100. Scoring was based on the average rating from the four test passages (i.e., 5 out of 10). The SIR test was chosen in order to assess subjective intelligibility of speech in noise.

Communication Confidence Profile

The Communication Confidence Profile (CCP) (Sweetow & Henderson Sabes 2010), a newly developed 12 item paper and pencil questionnaire will be used as a self-assessment tool to assess the participant's speech understanding and communication confidence for various listening situations. Specifically, the questionnaire was used pre and post auditory training to assess: 1. Communication in Quiet Listening Situations, 2. Action-taking to improve communication and 3. Communication in Adverse Listening Situations. The CCP uses a five point scale (i.e., 5 = extremely confident, 4 = strongly confident, 3 = moderately confident, 2 = slightly confident, and 1 = not at all confident) to measure the participants confidence in the above three areas. The participant was provided a Pocket Talker amplifier set at a designated comfortable listening level for pre-and-post training assessment. The participant was seated in a quiet room alongside the researcher who visually and orally reviewed each item prior to requesting the participant's item rating. The principal investigator manually recorded all responses on the written questionnaire form. The score for the test was represented by a total raw score determined by calculating the overall score for all the items on the questionnaire (i.e., 30 out of 60). The overall pre versus post raw scores can be categorized as follows: 50-60 = "Confident"; 40-50 = "Cautiously Certain"; 30- 39 = "Tentative" and 29-0 = "Insecure" (Sweetow & Henderson Sabes, 2010, p. 22).

Training and Control Conditions

Participants were randomly assigned placement in one of three groups (i.e., two auditory training groups and one control group). Participants in all three groups were asked to complete six 30-minute listening sessions at home in a one week period and then returned for follow-up testing.

Listening and Communication Enhancement (*LACE*)

One auditory training group were asked to complete six 30-minute sessions of the Listening and Communication Enhancement (LACE^{TM}) 4.0 program on DVD (Sweetow & Henderson Sabes, 2004; Neurotone Inc., 2007-2009) which includes: a) degraded speech training (i.e., speech in noise, rapid speech, competing voice) and b) cognitive training (i.e., missing word and word memory). In addition, LACE^{TM} 4.0 also offers periodic communication strategies throughout the training. The Listening and Communication Enhancement (LACE^{TM}) 4.0 (Sweetow & Henderson Sabes, 2004) full DVD version were used for up to three hours of training. This was included to allow for a comparison of training for the full DVD version (i.e., degraded speech plus cognitive modules of LACE^{TM} 4.0 with the degraded speech only training component within the LACE^{TM} 4.0 DVD (Neurotone, Inc. 2007-2009). This full DVD version of LACE^{TM} 4.0 training includes a compilation of various training components including degraded speech training (i.e., speech in noise, rapid speech, competing voice) cognitive training (i.e., missing word and word memory), and provides interactive communication strategies periodically throughout the training regiment (Sweetow & Henderson Sabes, 2007; LACE 4.0 Training Manual, 2009). The LACE^{TM} 4.0 program was used at the home of the participant who was randomly chosen for the LACE^{TM} 4.0 auditory training group. LACE^{TM} 4.0 components are randomly presented throughout the training regiment for a mixture of training elements. Participants in the LACE^{TM} 4.0 training group were provided a training notebook to follow during their six day training regiment. In addition, participants were given a LACE^{TM} 4.0 DVD and instructed to follow the training instructions as indicated on the LACE^{TM} training DVD program. On the day of the pre-training assessment, each participant was provided a tutorial for getting started with the DVD training prior to going home. Participants were advised to follow all training instructions as presented during the LACE^{TM} 4.0 training program and provided in the training notebook. Each participant also was instructed to train at a time of day when they were well rested and free from distractions. Participants were instructed to train for approximately 30 minutes a day for six days in a quiet environment with the television volume set at a comfortable listening level (Sweetow & Henderson Sabes, 2007; LACE 4.0 Training Manual, Neurotone 2007-2009). The degraded speech plus cognitive version of the LACE^{TM} 4.0 auditory-visual training program was used for up to three hours of training to assess degraded speech and cognitive abilities.

Listening and Communication Enhancement (Degraded Speech Condition)

A second group was asked to complete six 30-minutes sessions of only the degraded speech modules within the LACE^{TM} 4.0 training program (Neurotone, Inc. 2007-2009). This also was a DVD-based compact disk training program of degraded speech perceptual material based on the LACE^{TM} 4.0 platform. The LACE^{TM} 4.0 degraded speech only modules include: speech in noise, rapid speech, and competing speaker training. The degraded speech only modules of the LACE^{TM} 4.0 program also incorporate written communication strategies suggestions within each training segment. Participants in both LACE^{TM} 4.0 training groups (i.e., Degraded Speech only condition and the Degraded Speech plus Cognitive condition) conducted training using their own personal television and DVD systems while at home. In cases where the participants' personal DVD player does not play the DVD properly, a Magnavox DVD player was loaned to those participants via East Carolina University, Department of Communication Sciences and Disorders. Demonstration and instructions for installing the Magnavox DVD player was provided to the participant prior to loaning out the equipment. The degraded speech only LACE^{TM} 4.0 auditory-visual training program was used for up to three hours of training to assess degraded speech abilities. The training protocols and procedures used for the degraded speech only training was the same as those described from the LACE^{TM} 4.0 auditory training program.

Audio Books on Compact Disc

A third group served as controls who were asked to listen to short stories downloaded onto compact disk. These participants listened to the selected short stories for six days. Participants were provided a CD with a list of recorded audio books varying in genre that have listening lengths approximating 30 minutes per selection (www.librivox.org). Participants were instructed to listen to the audio book via a personal computer or stereo system with the volume set at a comfortable listening level. Participants were instructed to listen to the short stories at home in a quiet environment. In addition, participants were provided a training notebook with a list of the selected stories. The notebook also had three comprehension questions related to the short story for each of the six listening session. The purpose of the comprehension questions was to keep the control participants actively engaged in the training session. Prior to beginning this training program, each participant was provided with a disclaimer statement from the principal investigator advising the participant to contact the principal investigator for new training material, should they find any of the material inappropriate.

Statistical Methods

The statistical analysis tool used for all data collected in this experimental study is version 18 of the Statistical Package for the Social Sciences (SPSS) (SPSS Inc., an IBM Company), currently referred to as PASW Statistics 18. The analysis model for the data carried out in PASW Statistics 18 was a three group split-case multivariate analysis of variance (MANOVA) using Hotelling Trace statistic. Three split-case MANOVAs were conducted in order to examine whether there were significant differences in 1) speech perception, 2) cognitive processing, and 3) self-report occurring within the groups. The gate keeper or MANOVA used for this study has a relaxed level of significance ($p<0.10$); however, alpha for the individual tests (if MANOVA has $p \leq 0.10$) was still set at $p=0.05$. For the design of this study, all the multivariate tests are identical in the results.

The design of the study is a three independent group's randomization for pre and post between subject analyses (two auditory training groups and one control group) pre and post between subject analyses for outcomes obtained on 11 speech perceptual, 4 cognitive, and 8 self-report measures. For the design of this study, all the multivariate tests are identical in the results.

A pre study between groups contrast power analysis was run using a java applet from the Cancer Research and Biostatistics (CRAB) (http://www.crab.org/). Based on the java applet CRAB calculations, it was determined that a total of 60 participants, 20 participants per training group, would provide a power of 76% in a two tailed test at the 0.05 level of significance or 86% power for a one sided test relative to the three training groups for finding differences of ¾ to 1 standard deviation (i.e., moderate to large effect size) (http://www.crab.org/).

Prior to any formal analysis and hypothesis testing, all outcome measures were investigated using the Means and Explore descriptive statistics methods in SPSS. Furthermore, assumptions from the MANOVA were explored relative to independence of samples, normality and variance of the sample between groups/participants during the descriptive analysis. Pearson Product Moment correlation analyses were performed to determine the linear association between selected groups of variables. Box-plots and/or scatter plots were used to examine and display data as appropriate.

CHAPTER III

RESULTS

Participants

Eighty-five people ages 60 to 80 years old were initially tested for potential participation. Of those, 49 did not qualify due to one or more of the following: 1) interaural pure-tone asymmetry greater than 15 dB in the designated frequency range of 500-4000 Hz; 2) abnormal tympanometry results and/or 3) absent or elevated contralateral acoustic reflex thresholds. Thirty-six participants completed the initial test session and were randomly assigned to one of three training groups: 1) LACE 4.0, 2) LACE-Degraded, or 3) Librivox-short story listening. Of those 36 participants, two had interaural pure-tone asymmetry greater than 15 dB at 4000 Hz only. Those two participants were included in the study based on review of criteria from Humes et al. (2006) which allowed for greater asymmetry at 4000 Hz. In addition, one participant who completed the initial test session was lost to follow up. Therefore, data analysis was conducted on measures from the 35 participants who completed the entire study (i.e., initial testing, six days of listening training and the post-training test session). The majority of participants (N=27) completed approximately 180 minutes (i.e., 30 minutes a day) of training via either DVD or CD over the six days. However, due to technical errors with some equipment and the training DVD, a few participants (N=8) completed between 170-175 minutes of training.

Table 1 displays the descriptive statistics means and standard deviations for gender, age, age range, and hearing loss characteristics for each group.

Table 1: Group Descriptive Statistics for Age, Gender and Hearing Loss Characteristics

Group	Gender	Ages	RT Ear Hearing Loss 1, 2, 4 kHz PTA	LT Ear Hearing Loss 1, 2, 4 kHz PTA
LACE 4.0	F = 9	Range: 62 – 78 Mean: 70.8 (SD 6.12)	Range: 20-42 dB HL Mean: 28.8 (SD 7.19)	Range: 22-35 dB HL Mean: 27.3 (SD 5.29)
	M = 3	Range: 62 – 71 Mean: 63.3 (SD 4.73)	Range: 18-23 dB HL Mean: 21.0 (SD 2.65)	Range: 18-25 dB HL Mean: 21.0 (SD 3.61)
Degraded	F = 6	Range: 64 – 74 Mean: 70.2 (SD 4.45)	Range: 18-32 dB HL Mean: 25.2 (SD 4.88)	Range: 13-32 dB HL Mean: 21.3 (SD 7.74)
	M = 6	Range: 65 – 78 Mean: 70.5 (SD 6.22)	Range: 13-42 dB HL Mean: 24.7 (SD 11.40)	Range: 15-47 dB HL Mean: 27.3 (SD 11.70)
Librivox	F = 7	Range: 62 – 79 Mean: 69.1 (SD 5.24)	Range: 22-47 dB HL Mean: 34.1 (SD 9.99)	Range: 25-48 dB HL Mean: 33.9 (SD7.65)
	M = 4	Range: 61 – 74 Mean: 66.5 (SD 5.80)	Range: 15-27 dB HL Mean: 22.3 (SD 5.25)	Range: 17-27 dB HL Mean: 22.0 (SD 5.77)

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Multivariate analysis of variance (MANOVA) was conducted to determine if there was a significant difference in age or hearing loss between study groups. No significant differences ($p > 0.05$) were found for age or hearing loss between groups ($p=.958$) in all cases. The full MANOVA is found in Appendix F. Figures 1 and 2 represent the average (± 1 SD) air conduction thresholds from 250-6000 Hz for the participants' right and left ears, respectively. These figures illustrate the typical sloping configuration seen in older adults with hearing loss.

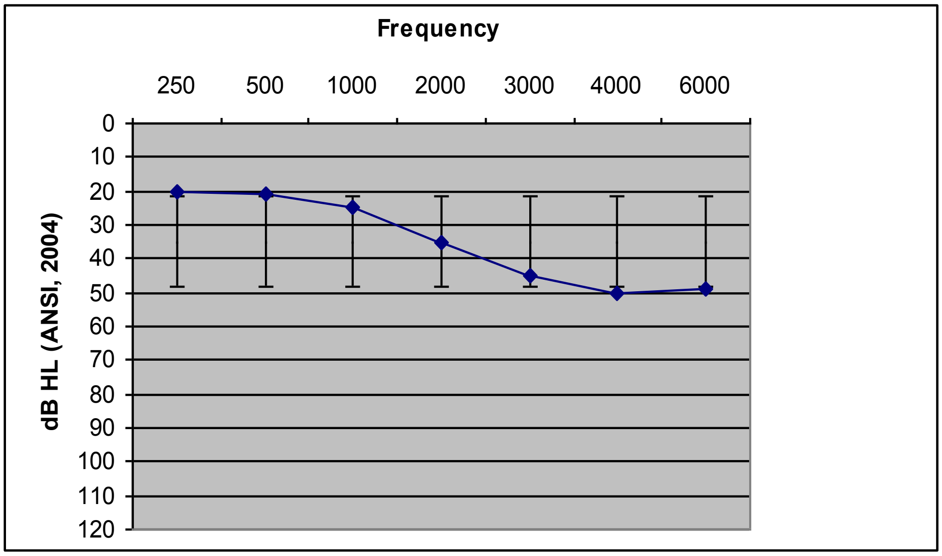

Figure 1: Average Right Ear Air Conduction Thresholds for All Participants

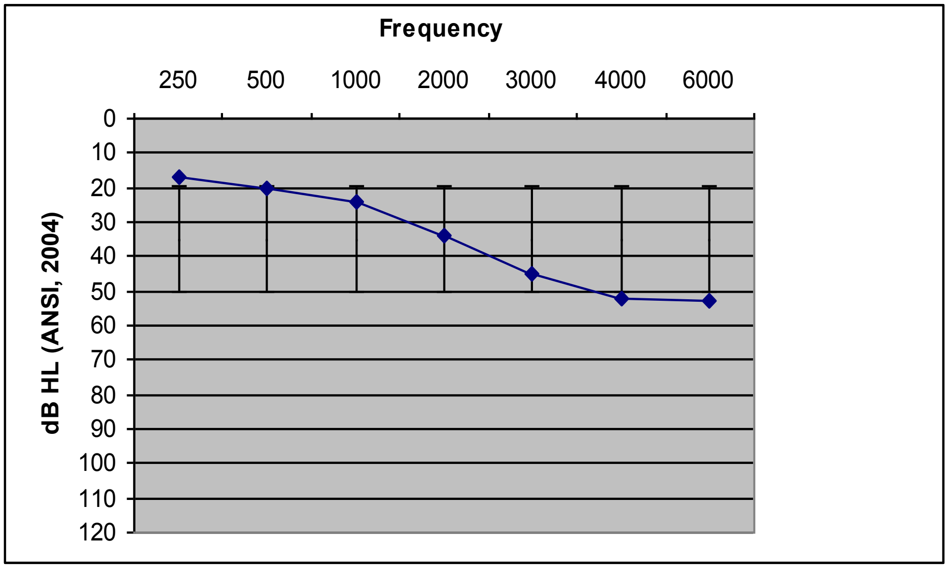

Figure 2: Average Left Ear Air Conduction Thresholds for All Participants

The characteristics of the participants prior to training were of interest. Therefore, three MANOVAs were run to confirm that there were no significant differences across groups prior to training in speech perception as measured by syllable, word and sentence identification in either degraded or dichotic conditions, cognition as measured by indices of divided attention, working memory and processing speed, or self-reported communication as measured by ratings of self-perceived function in average and adverse listening conditions, use of verbal and non-verbal strategies as well as discouragement and stress related to hearing difficulties, judgment of proportion of words understood in a passage and self-perceived communication confidence. No significant differences in these abilities were found ($p<0.10$) across groups prior to training. Specifically the p-value for the speech perceptual measures was $p=.248$, the p-value for the cognitive processing measures was $p=.524$ and the p-value for the self-report measures was $p=.351$. The full MANOVA tables are found in Appendix G, H, and I respectively.

Descriptive Statistics for Research Measures

Descriptive statistics were used to establish the means and standard deviation for research measures in the following three training groups: 1) Listening and Communication Enhancement (LACE 4.0), 2) LACE-Degraded, and 3) Librivox short story control task. All scores used in the analysis were raw or average scores with descriptive statistic tables, box-plots and MANOVA data of these measures offered below.

Descriptive Statistics for Speech Perceptual Measures

Tables 2 & 3 offer the means and standard deviations for the six speech perceptual measures for a total of 11 scored conditions.

Table 2: Means, Standard Deviations and Ranges for the Pre and Post Training Raw Scores on the WIN, CST, DSI and TC

Speech Perceptual Test Measures	**N**	**Group**	**Mean (Std. Dev) Pre**	**Post**	**Range Pre**	**Post**
Words in Noise (WIN) Better Ear Score	12	LACE 4.0	20.08 (3.55)	21.60 (4.48)	15–27	13-27
	12	Degraded	18.00 (3.33)	17.58 (2.84)	11-21	13-22
	11	Librivox	20.18 (3.82)	18.91 (4.99)	14-25	9-26
Connected Speech Test (CST) Better Ear Score	10	LACE 4.0	63.90 (18.35)	61.50 (19.01)	31-95	29-95
	10	Degraded	57.85 (13.74)	66.70 (11.64)	31-83	45-86
	11	Librivox	60.27 (11.11)	62.91 (16.43)	42-79	36-86
Dichotic Sentence Identification (DSI) Right Ear Score	12	LACE 4.0	27.60 (2.46)	28.92 (1.17)	22-30	26-30
	11	Degraded	28.27 (1.56)	29.36 (0.81)	25-30	28-30
	11	Librivox	29.27 (1.01)	29.36 (1.21)	27-30	26-30
Dichotic Sentence Identification (DSI) Left Ear Score	12	LACE 4.0	25.17 (4.57)	27.50 (2.84)	16-30	22-30
	11	Degraded	26.36 (3.80)	27.82 (1.78)	17-29	24-30
	11	Librivox	28.91 (1.58)	28.91 (2.02)	26-30	24-30
Time Compressed Speech (TC) Better Ear Score	12	LACE 4.0	16.33 (9.88)	19.08 (9.31)	0-30	5-37
	12	Degraded	13.42 (6.72)	13.17 (6.65)	4 -27	3-26
	11	Librivox	15.45 (8.02)	17.55 (7.95)	0-25	4-33

Table 3: Means, Standard Deviations and Ranges for Pre and Post Training Scores on the DDT-Free Recall, DDT-Directed Recall, i-CAST Time and i-CAST Syllable Identification

Speech Perceptual Test Measures	**N**	**Group**	**Mean (Std. Dev)**		**Range**	
			Pre	**Post**	**Pre**	**Post**
Dichotic Digits Triplets (DDT) Free Recall - Right Ear Score	12	LACE 4.0	60.08 (8.31)	60.83 (10.07)	37-69	42-73
	12	Degraded	60.17 (6.74)	61.17 (7.31)	51-71	50-71
	11	Librivox	65.09 (6.83)	66.91 (4.51)	55-73	60-72
Dichotic Digits Triplets (DDT) Free Recall - Left Ear Score	12	LACE 4.0	43.58 (13.66)	46.25 (9.50)	24-66	31-63
	12	Degraded	46.00 (7.03)	54.75 (7.56)	35-58	39-64
	11	Librivox	46.45 (11.31)	52.27 (7.31)	26-69	40-66
Dichotic Digits Triplets (DDT) Directed Recall - Right Ear- Score	12	LACE 4.0	35.17 (7.95)	35.67 (9.01)	17-42	15-47
	12	Degraded	33.25 (6.61)	36.92 (7.17)	25-47	26-50
	11	Librivox	36.18 (8.59)	38.64 (7.50)	24-49	28-50
Dichotic Digits Triplets (DDT) Directed Recall - Left Ear Score	12	LACE 4.0	28.33 (9.26)	30.42 (8.66)	15-41	17-44
	12	Degraded	29.75 (7.76)	33.58 (6.11)	15-38	25-45
	11	Librivox	29.82 (6.88)	31.91 (7.50)	16-40	19-43
Internet-Based Computer Assisted Speech Training (i-CAST) Time in Minutes Binaural Score	12	LACE 4.0	16.83 (1.99)	16.17 (1.80)	14-21	13-19
	12	Degraded	17.50 (2.20)	16.50 (2.15)	14-21	14-21
	11	Librivox	17.00 (4.15)	15.55 (2.02)	13-28	13-20
Internet-Based Computer Assisted Speech Training (i-CAST) RAW Score Binaural Score	12	LACE 4.0	161.92 (20.04)	167.25 (18.62)	120-189	125-187
	12	Degraded	159.67 (18.80)	166.92 (14.75)	130-184	140-189
	11	Librivox	169.82 (12.58)	172.91 (9.99)	148-185	158-185

Figures 3-11 are box-plot displays of the pre and post training speech scores for each of the 11 speech measures by training group. Overall, the box-plots show some possible signs of improvement with auditory training. Another key aspect in these plots is the variability in scores within the groups. Ideally, each box-plot would include data for all scores on a given test for each group (e.g., DDT, right FR; DDT, left FR; DDT right DR and DDT left DR). However, this did not allow for easy visualization of the data. In those instances, multiple box-plots were used to display the results. In addition, outliers are present in the majority of box-plots. The outliers were statistically determined to be the data points that lie outside of the minimum and maximum ranges of the primary data set.

Figure 3 is a box-plot with the raw scores for the three test groups on the WIN, a test on which scores may range from 0 to 35.

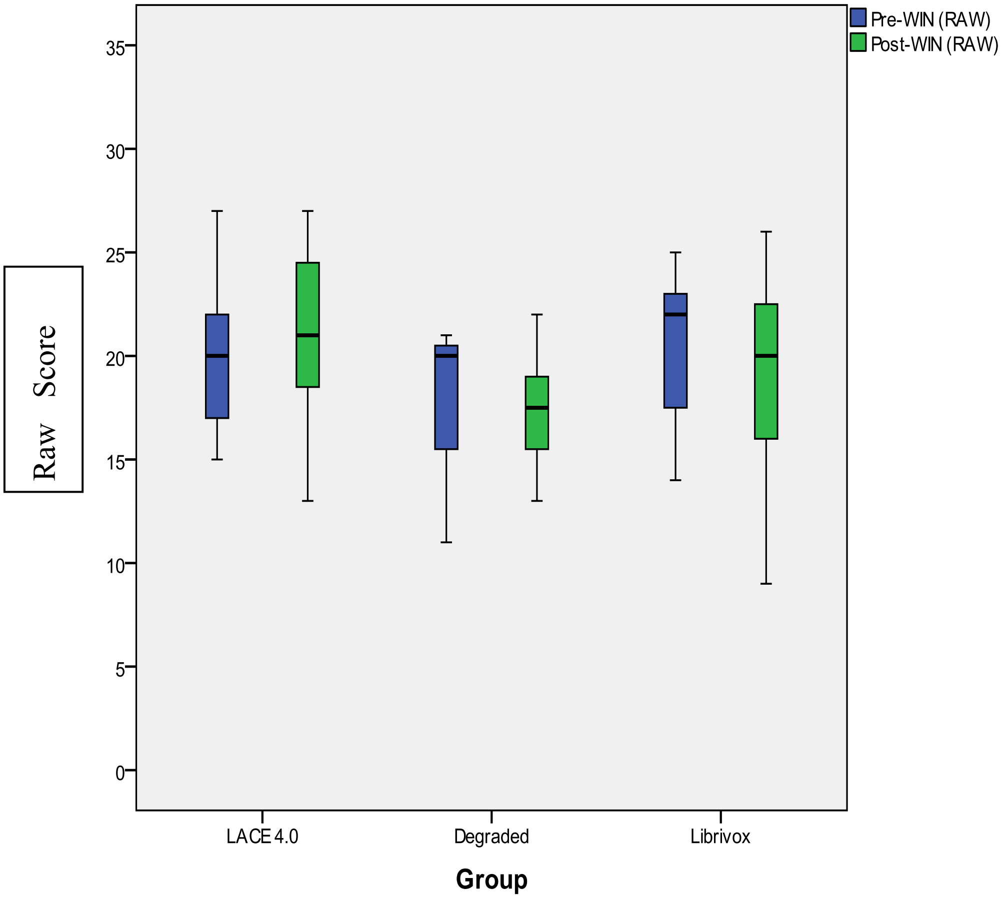

Figure 3: Pre and Post Training Scores for the WIN Test for the Three Groups

Pre-WIN (RAW) = Raw scores for the Words in Noise test prior to listening training; Post-WIN (RAW) = Raw scores for the Words in Noise test following listening training

The only group showing a higher median score after training on the WIN test is the LACE 4.0 training group.

Figure 4 is a box-plot with the raw scores for the three test groups on the CST, a test on which scores may range from 0 to 100.

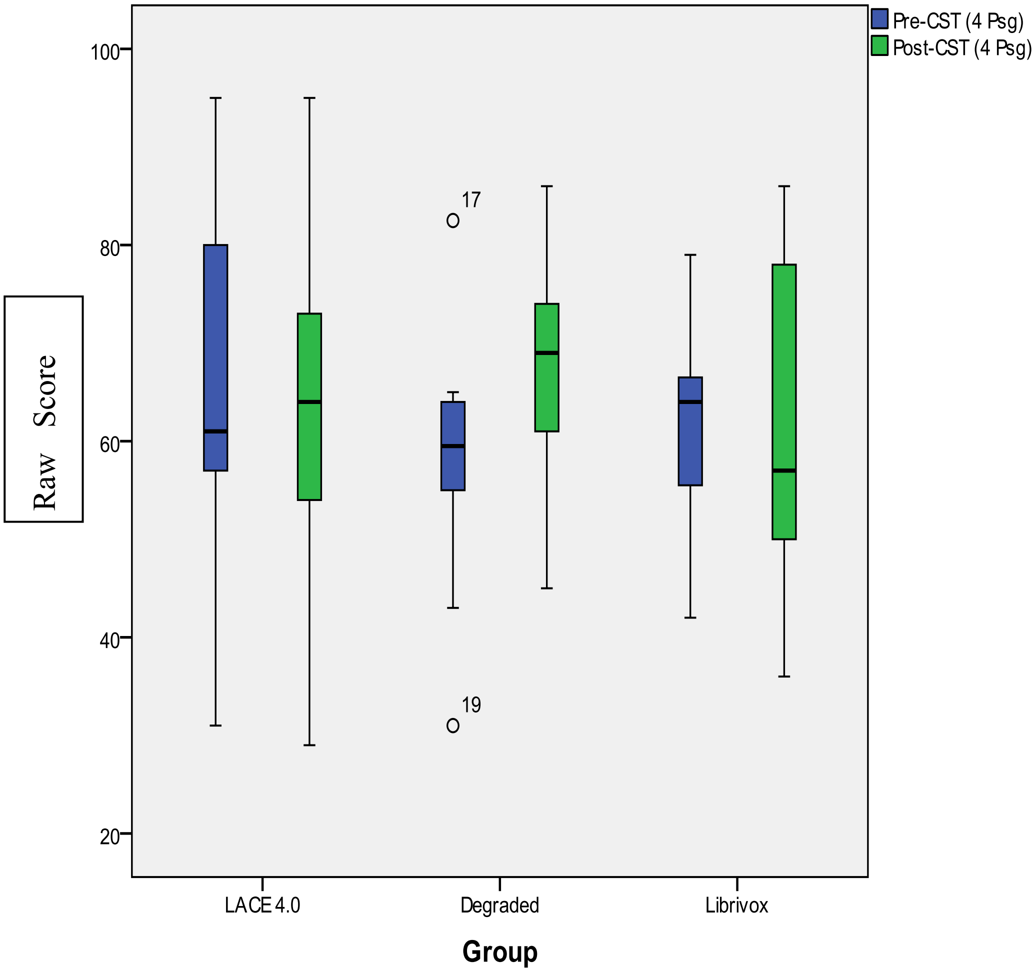

Figure 4: Pre and Post Training Scores for the CST Test for the Three Groups

Pre-CST (4 Psg) = Average scores calculated from 4 passages on the Connected Speech Test prior to listening training; Post- CST (4 Psg) = Average scores calculated from 4 passages on the Connected Speech Test following listening training; numbers 17 and 19 near the outlier markers reflect the case numbers from the database

The LACE 4.0 and LACE Degraded groups showed higher median scores post training on the CST.

Figure 5 is a display with the raw scores for the three test groups for the right ear on the DSI, a test on which scores may range from 0 to 30.

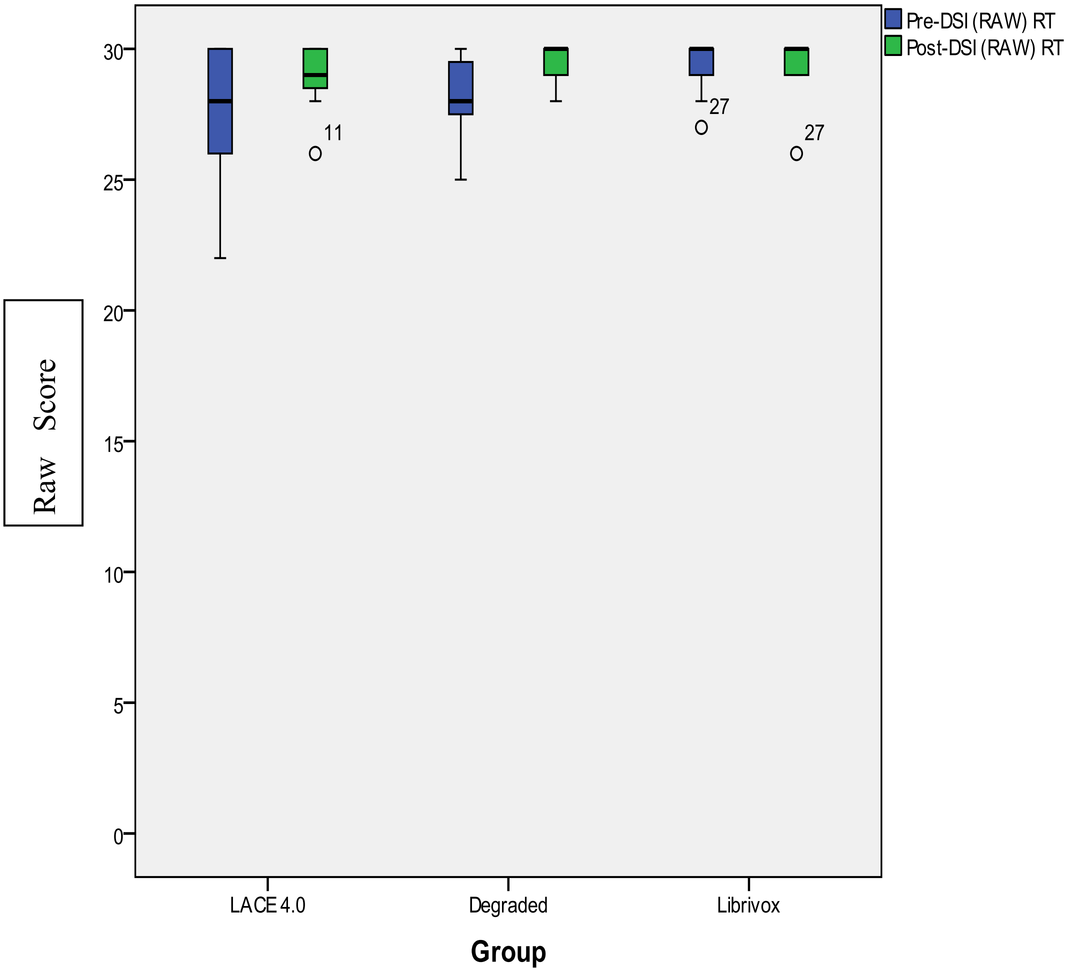

Figure 5: Pre and Post Training Scores for the Right Ear on the DSI Test for the Three Groups

Pre-DSI (RAW) RT = Raw scores for the right ear on the Dichotic Sentence Identification test prior to listening training; Post- DSI (RAW) RT = Raw scores for the right ear on the Dichotic Sentence Identification test following listening training; numbers 11 and 27 near the outlier markers reflect the case numbers from the database; One extreme outlier (#19 from the database) was removed prior to analysis as this data point represented an individual who could not initially perform the DSI task without repeated prompting, pausing and re-starting the test

The DSI scores for the right ear show a possible ceiling effect in all groups on the pre-training and post-training measures.

Figure 6 is a display with the raw scores for the three test groups for the left ear on the DSI, a test on which scores may range from 0 to 30.

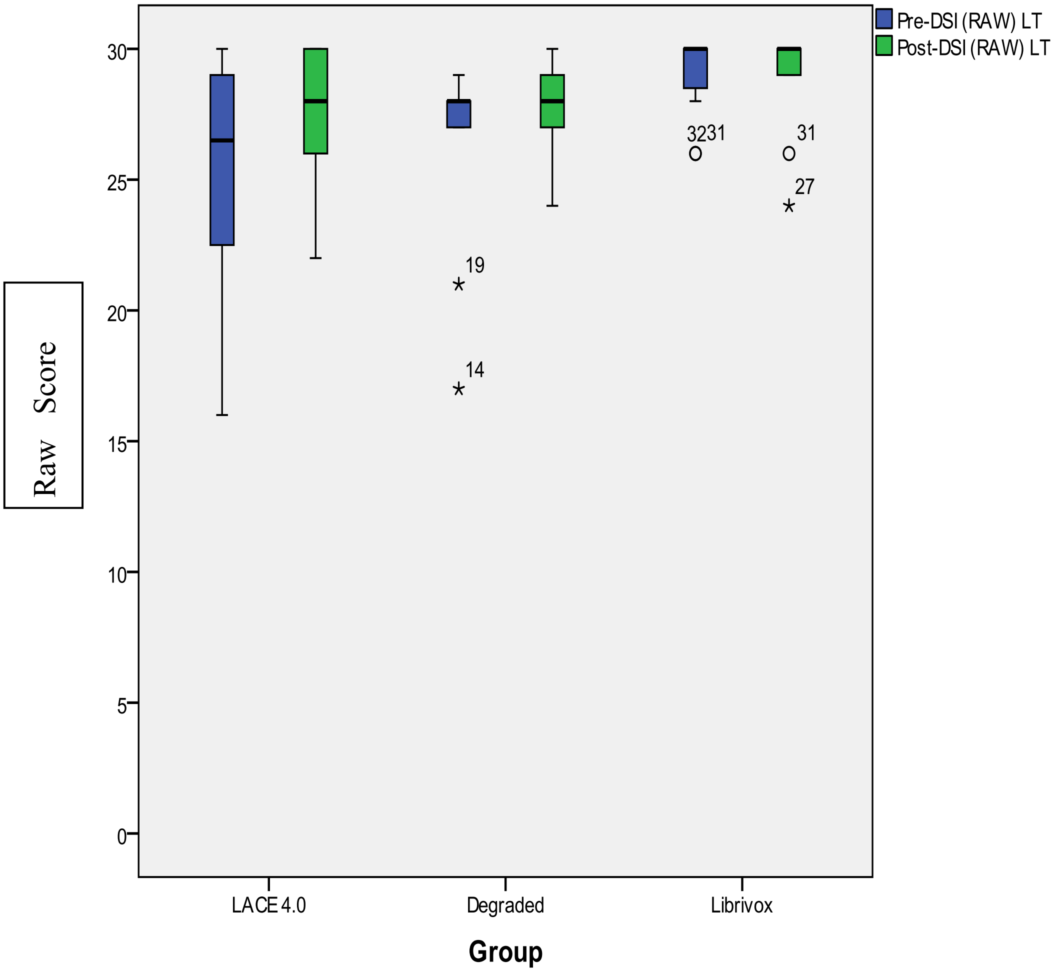

Figure 6: Pre and Post Training Scores for the Left Ear on the DSI Test for the Three Groups

Pre-DSI (RAW) LT = Raw scores for the left ear on the Dichotic Sentence Identification test prior to listening training; Post- DSI (RAW) LT = Raw scores for the left ear on the Dichotic Sentence Identification test following listening training; numbers 14, 19, 27, 31 and 32 near the outlier markers reflect the case numbers from the database; *14,*19 and *27 = extreme outliers; Extreme outlier *19 represents an individual who could not initially perform the DSI task

Test scores on the DSI for the left ear show a possible ceiling effect in all groups on the pre-training and post-training measures; and a smaller range of scores in the Librivox group. The LACE 4.0 and LACE Degraded groups showed higher median scores post training.

Figure 7 is a display with the raw scores for the three test groups on the TC, a test on which scores may range from 0 to 50.

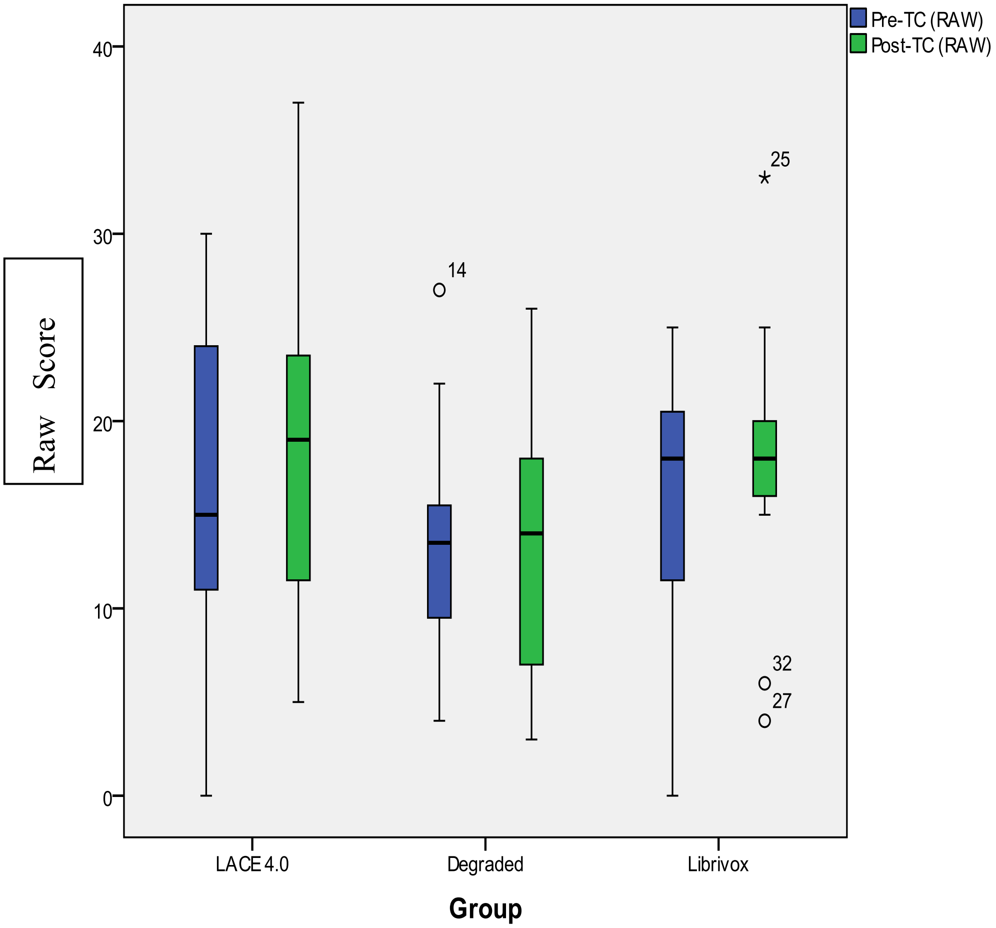

Figure 7: Pre and Post Training Scores for the TC Test for the Three Groups

Pre-TC (RAW) = Raw scores for the Time-Compressed Speech test prior to listening training; Post-TC (RAW) = Raw scores for the Time-Compressed Speech test following listening training; numbers 14, 25, 27 and 32 near the outlier markers reflect the case numbers from the database; *25 = extreme outlier

The only group showing a higher median score post-training on the Time Compressed Speech Test is the LACE 4.0 group.

Figure 8 is a display with the raw scores for the three test groups for the right and left ears on the DDT Free-Recall test, a test on which scores may range from 0 to 75.

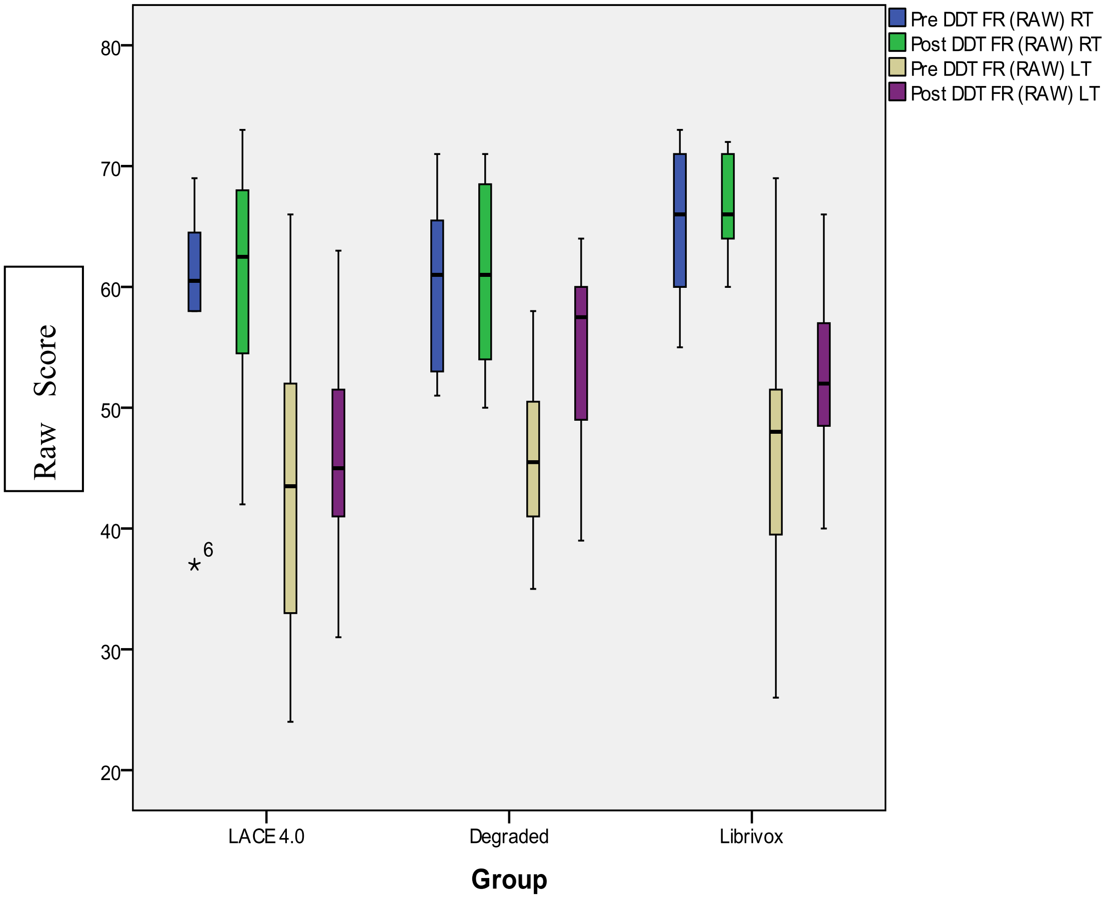

Figure 8: Pre and Post Training Scores for the Right and Left Ear for the DDT-Free Recall Test for the Three Groups

Pre-DDT FR (RAW) RT = Raw scores for the right ear on the Dichotic Digits Triplets test Free-Recall test prior to listening training; Post-DDT FR (RAW) RT = Raw scores for the right ear on the Dichotic Digits Triplets test Free-Recall test following listening training; Pre-DDT FR (RAW) LT = Raw scores for the left ear on the Dichotic Digits Triplets test Free-Recall test prior to listening training; Post-DDT FR (RAW) LT = Raw scores for the left ear on the Dichotic Digits Triplets test Free-Recall test following listening training; number *6 = extreme outlier that reflects the case number from the database

There are higher median scores post training for the right and left ear scores for free recall tasks in the LACE 4.0 group, and higher median scores post training for the left ear scores for the free recall task in the LACE Degraded and Librivox groups.

Figure 9 is a display with the raw scores for the three test groups for the right and left ears on the DDT Directed-Recall test, a test on which scores may range from 0 to 54.

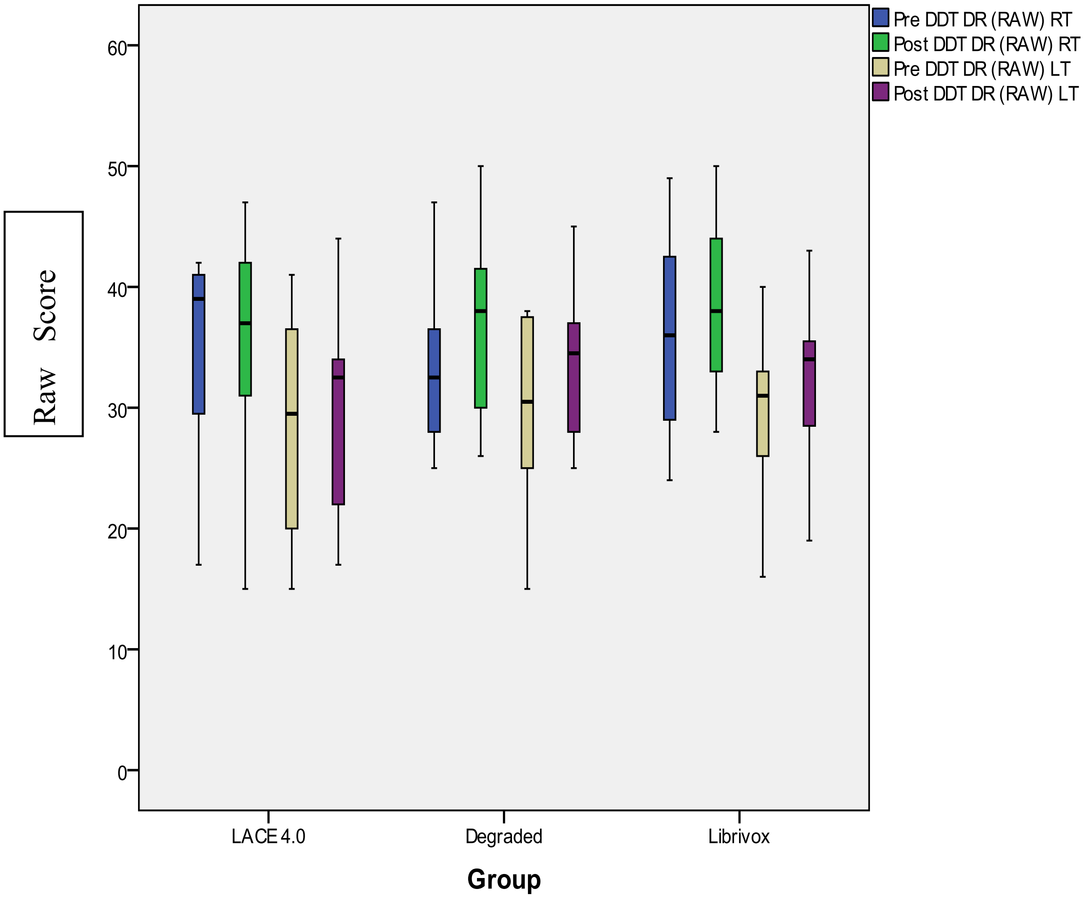

Figure 9: Pre and Post Training Scores for the Right and Left Ears for the DDT-Directed Recall Test for the Three Groups

Pre-DDT DR (RAW) RT = Raw scores for the right ear on the Dichotic Digits Triplets test Directed-Recall test prior to listening training; Post-DDT DR (RAW) RT = Raw scores for the right ear on the Dichotic Digits Triplets Directed-Recall test following listening training; Pre-DDT DR (RAW) LT = Raw scores for the left ear on the Dichotic Digits Triplets Directed-Recall test prior to listening training; Post-DDT DR (RAW) LT = Raw scores for the left ear on the Dichotic Digits Triplets Directed-Recall test following listening training

There are higher median scores post-training for all groups on the directed recall task with the exception of the right ear score for the directed recall task in the LACE 4.0 group.

Figure 10 is a display with time completion in minutes for the i-CAST, which in this population ranged up to 26 minutes.

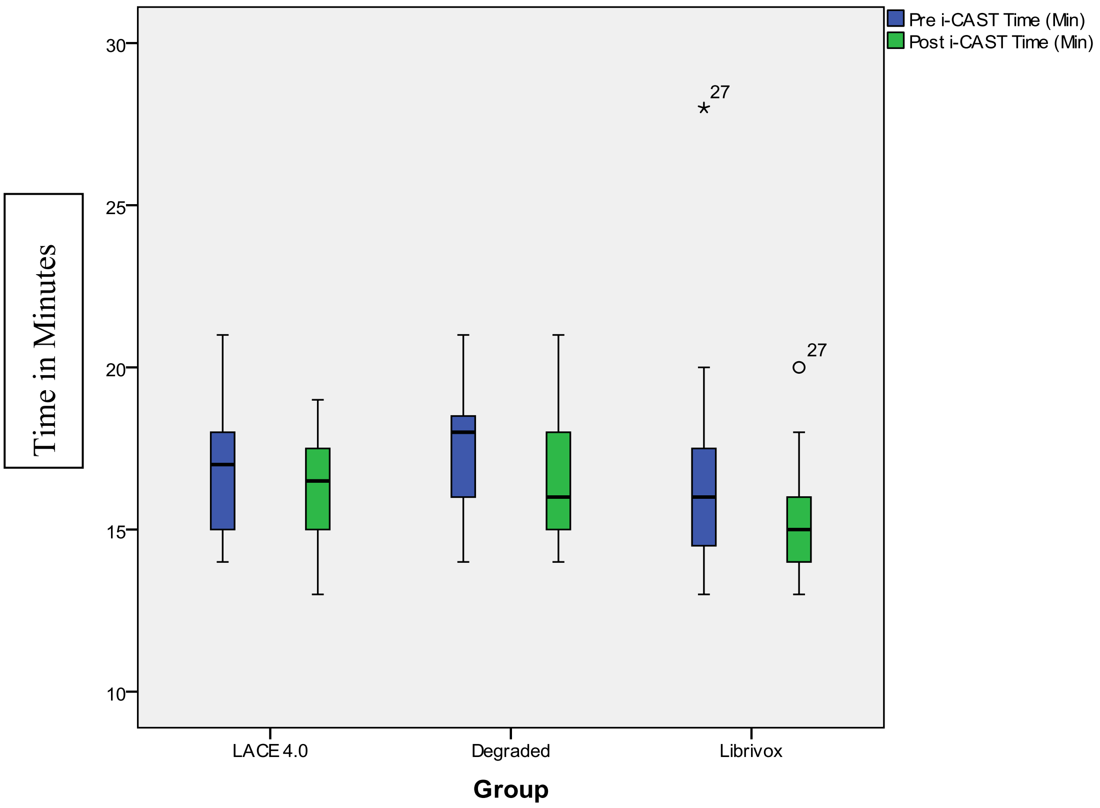

Figure 10: Pre and Post Training Scores for the i-CAST Time in Minutes for the Three Groups

Pre-i-CAST Time (Min) = Time scores in minutes for the Internet-Based Computer Assisted Training test prior to listening training; Post- i-CAST Time (Min) = Time scores in minutes for the Internet-Based Computer Assisted Training test following listening training; number 27 near the outlier markers reflect the case number from the database; *27 = extreme outlier

This figure reflects completion time on the i-CAST task and a lower time reflects possible improvement. The median scores are lower across groups demonstrating reduced task completion time when comparing post-training to pre-training measures.

Figure 11 is a display with the raw scores for the i-CAST syllable identification test, a test on which scores may range from 0 to 200.

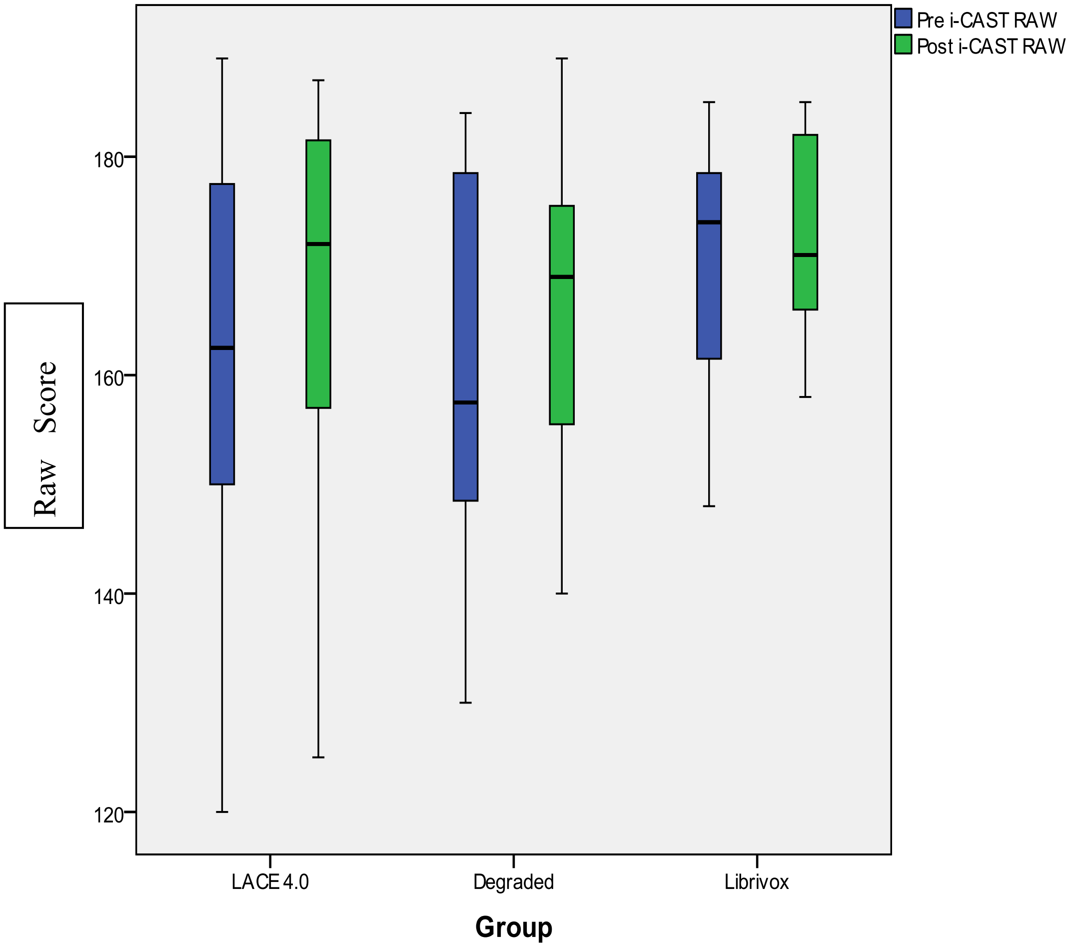

Figure 11: Pre and Post Training Scores for the i-CAST Syllable Identification for the Three Groups

Pre-i-CAST (RAW) = Raw scores for the Internet-Based Computer Assisted Training test prior to listening training; Post- i-CAST (RAW) = Raw scores for the Internet-Based Computer Assisted Training test following listening training

There are higher median scores after training on the i-CAST syllables in the LACE 4.0 and LACE Degraded Groups.

Research Question 1: Are there significant changes on test measures following training?

A series of MANOVAs were conducted in order to examine whether there were significant differences in speech perception as measured by syllable, word and sentence identification in either degraded or dichotic conditions; cognition as measured by indices of divided attention, working memory and processing speed; or self-reported communication as measured by ratings of self-perceived function in average and adverse listening conditions, use of verbal and non-verbal strategies as well as discouragement and stress related to hearing difficulties, judgment of proportion of words understood in a passage and self-perceived communication confidence occurring within the groups following training.

These MANOVAs are found in Appendices J-U. No significant differences were found at $p<0.05$. Because the study sample was small and the power of these tests was low, the level of significance for all of the MANOVAs was relaxed to $p<0.10$ as advised by the statistician. If the MANOVA was found to be significant ($p<0.10$) then an examination of individual tests at the $p<0.05$ level was undertaken with designation of the p-values obtained.

MANOVAs to Explore for Changes in Speech Perceptual Measures

Three individual MANOVAs were run to examine for possible pre to post training differences in speech perceptual measures as measured by syllable, word and sentence identification in either degraded or dichotic conditions for the test groups. In the LACE 4.0 training group, the MANOVA results for the Hotelling's Trace statistic revealed a statistically significant pre-post difference in speech perception ($p = .082$). Statistically significant differences were found on the following tests: DSI right ear ($p = .018$), DSI left ear ($p = .030$), TC (p = .041), and i-CAST Time (p = .025). The full MANOVA and Tests of Between-Subjects Effects for the LACE 4.0 group are found in Appendix J and K, respectively.

For the LACE-Degraded training group, Hotelling's Trace statistic (p = .345) was not significant at the relaxed p-value of p<0.10 and therefore no further examination was conducted. The full MANOVA for the LACE-Degraded group is found in Appendix L.

For the Librivox group, Hotelling's Trace statistic (p = .454) was not significant at the relaxed p-value of p<0.10 and therefore no further examination was conducted. The full MANOVA for the Librivox group is found in Appendix M.

MANOVAs to Explore Change Scores in Speech Perceptual Measures Between Groups.

A MANOVA was run to examine the change scores following training for possible significant differences in speech perceptual measures as measured by syllable, word and sentence identification in either degraded or dichotic conditions between groups. The MANOVA results for the Hotelling's Trace statistic revealed a statistically significant (p <.05) post-training difference in speech perception (p = .045) between groups. The full MANOVA is found in Appendix N. Pair wise comparison and interaction plots revealed a statistically significant speech perceptual difference between the LACE 4.0 and Degraded groups (p = .029) on the CST test; a statistically significant speech perceptual difference between the LACE 4.0 and Librivox groups (p = .027) on the DSI right ear test; a statistically significant speech perceptual difference between the Degraded and Librivox groups (p = .026) on the DSI right ear test; a statistically significant speech perceptual difference between the LACE 4.0 and Librivox groups (p = .037) on the DSI left ear test and a statistically significant speech perceptual difference between the LACE 4.0 and Degraded groups (p = .002) on the DDT Free Recall left ear test. Figures 12 – 15 display the box-plots for change scores between these groups and speech perceptual measures.

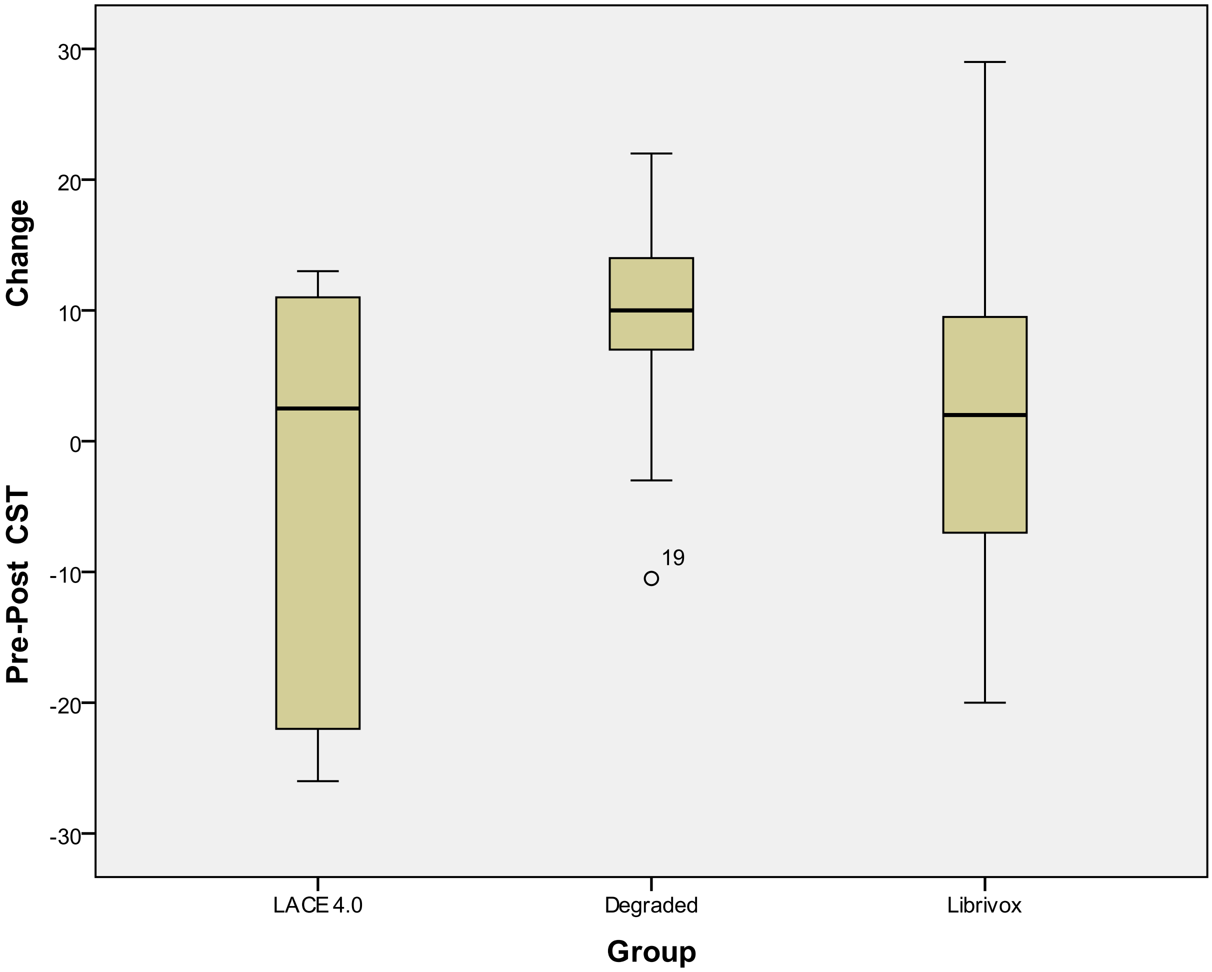

Figure 12: Box-plot for Change Scores Following Training on the CST

The number 19 near the outlier marker reflects the case number from the database

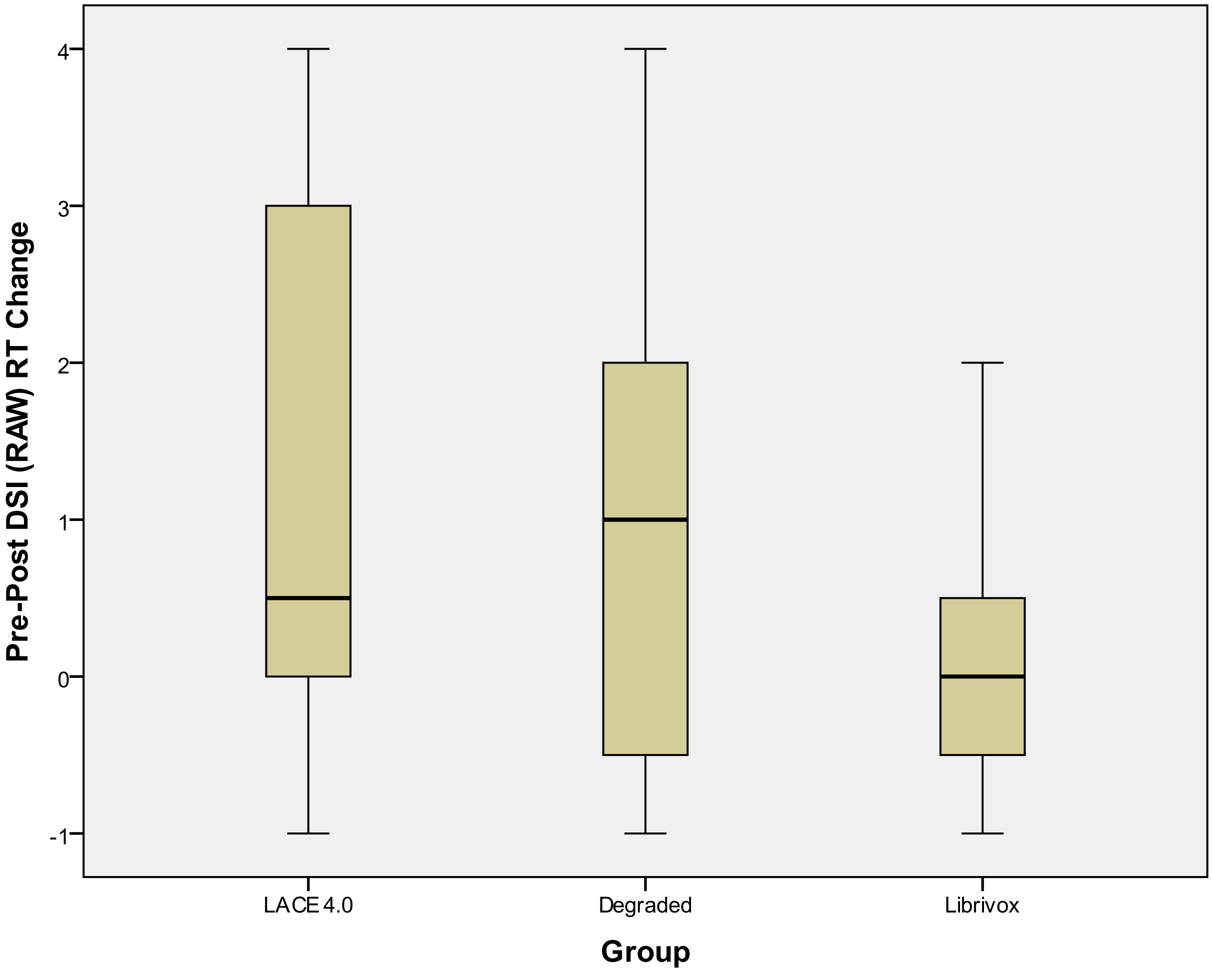

Figure 13: Box-plot for Change Scores Following Training for the DSI Right Ear

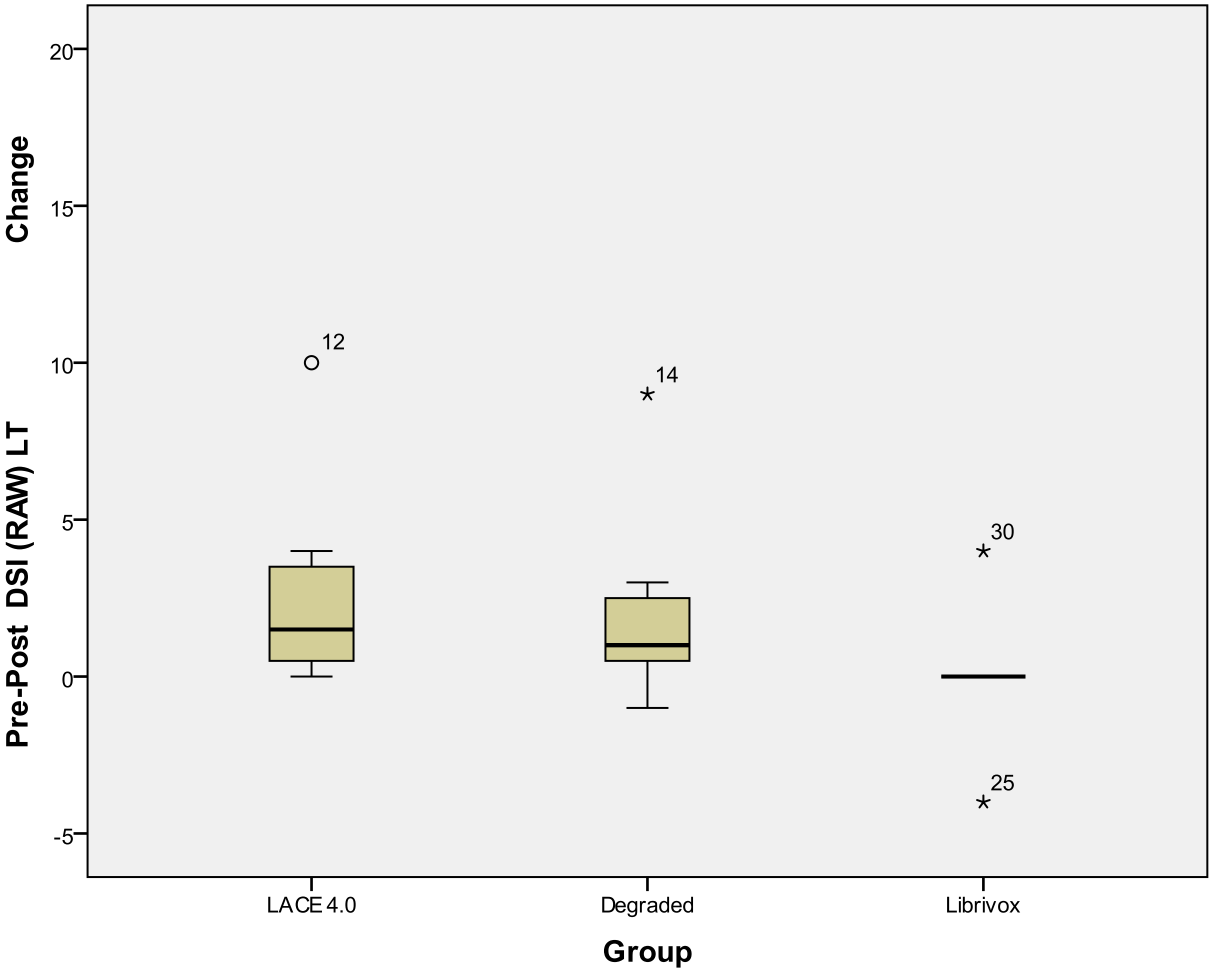

Figure 14: Box-plot for Change Scores Following Training for the DSI Left Ear

The numbers 12, 14, 25 and 30 near the outlier markers reflect the case numbers from the database; *14, *25 and *30 = extreme outliers; one extreme outlier *13 for the Degraded group is not graphed to allow for better visualization of the change scores

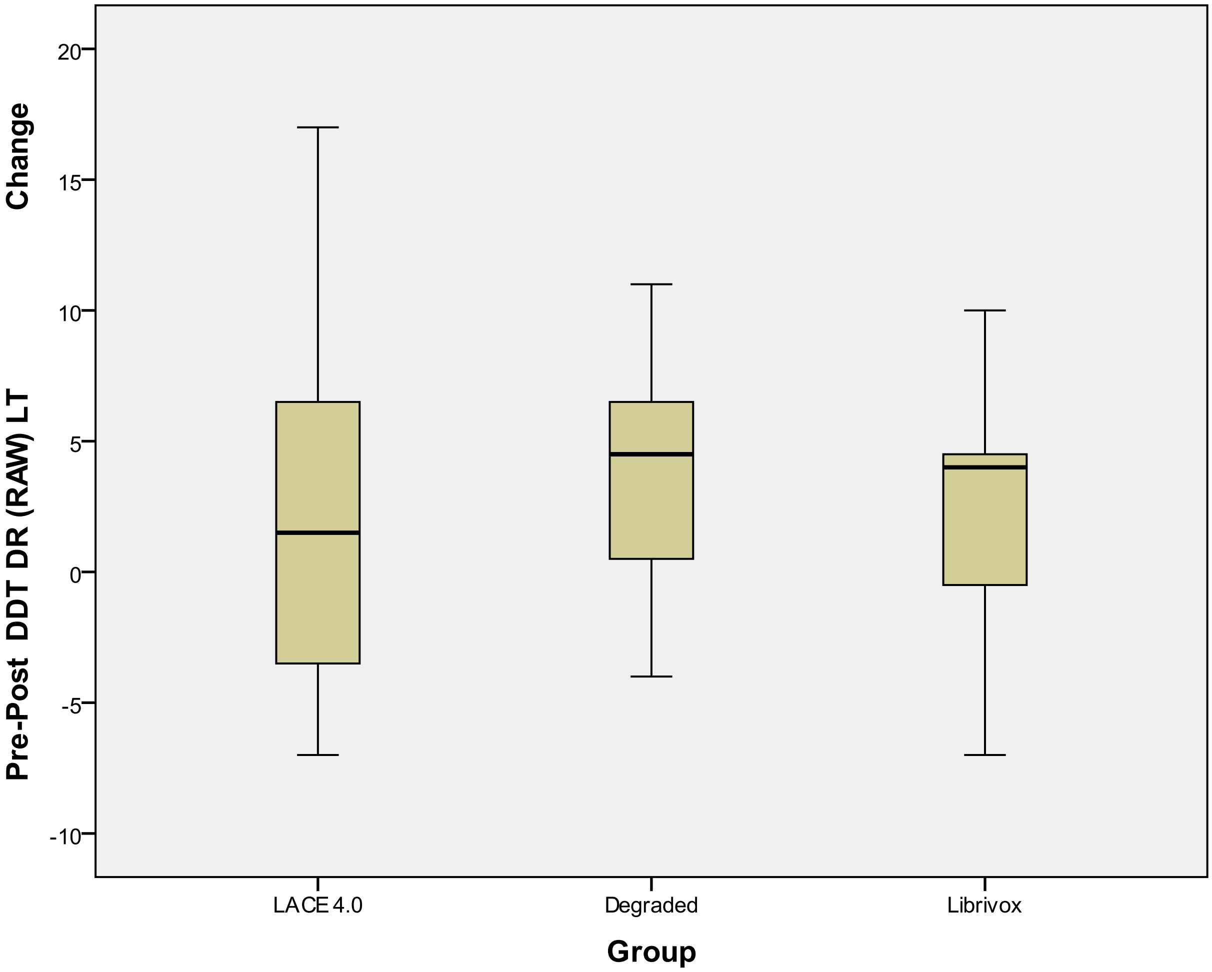

Figure 15: Box-plot for Change Scores Following Training for the DDT FR Left Ear

Descriptive Statistics for the Cognitive Measures

Cognitive measures included the following: Brief Test of Attention (BTA) (Schretlen, 2009), Numbers Reversed Test (NR) (Mather & Woodcock, 2001) and the Auditory Choice Reaction Time Test (ARTT) (SuperLab Pro 4.0; Cedrus Corporation, 2008). Table 6 offers the descriptive statistics for the pre and post training scores on the cognitive processing measures (BTA, NR and ARTT). Figures 16-19 are box-plots graphically displaying the pre and post training scores on the cognitive measures for each group.

Table 4: Means, Standard Deviations and Ranges for Pre and Post Training Scores on the Cognitive Processing Measures for the Three Groups

Cognitive Processing Test Measures	**N**	**Group**	**Mean (Std. Dev)**		**Range**	
			Pre	**Post**	**Pre**	**Post**
Brief Test of Attention (BTA) Binaural	12	LACE 4.0	14.83 (3.22)	15.08 (3.09)	9-19	9-19
	12	Degraded	15.58 (2.47)	14.58 (3.03)	11-19	9-20
	11	Librivox	14.82 (3.79)	14.91 (4.18)	9-20	9-20
Numbers Reversed Test (NR) Binaural	12	LACE 4.0	12.00 (2.73)	12.42 (2.07)	6-17	10-17
	12	Degraded	13.67 (3.58)	13.33 (3.26)	9-22	9-20
	12	Librivox	13.82 (2.79)	14.18 (3.19)	10-20	10-21
Auditory Choice Reaction Time (ARTT) in Milliseconds Binaural	11	LACE 4.0	322.17 (584.97)	149.75 (56.50)	95.2-2082.5	78-262.6
	12	Degraded	177.23 (168.35)	126.30 (47.14)	27.1-677.03	61.5-209.2
	11	Librivox	131.22 (44.34)	119.75 (37.04)	47-202.3	70.8-190.7
Auditory Choice Reaction Time (ARTT) Raw Score Binaural	11	LACE 4.0	20.55 (7.59)	17.82 (7.33)	8-30	1-28
	12	Degraded	18.75 (8.65)	20.42 (5.92)	5-30	12-29
	11	Librivox	13.55 (9.02)	12.91 (6.12)	1-28	4-27

Figure 16 is a display with the raw scores for the three test groups on the BTA, a test on which scores may range from 0 to 20.

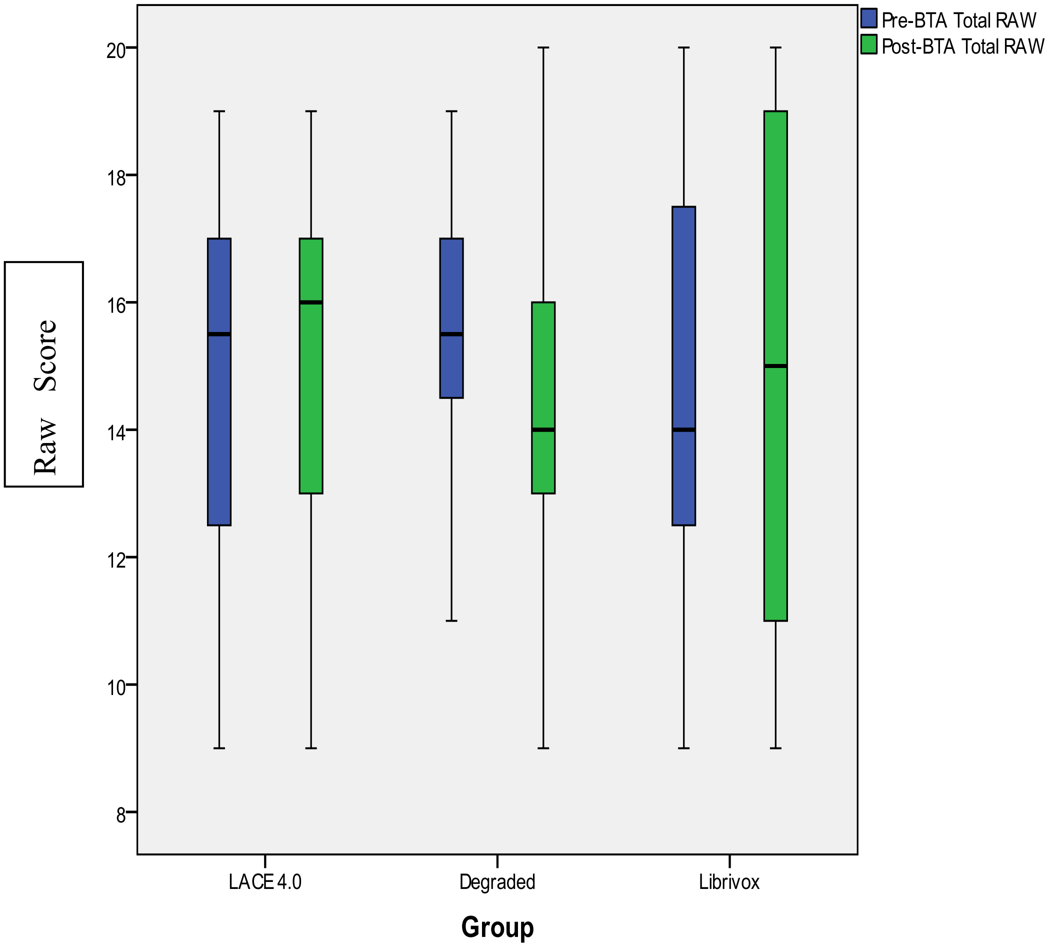

Figure 16: Pre and Post Training Scores for the BTA Test for the Three Groups

Pre-BTA Total RAW = Raw scores for the Brief Test of Attention test prior to listening training; Post- BTA Total RAW = Raw scores for the Brief Test of Attention test following listening training

There are higher median scores for the LACE 4.0 and Librivox groups relative to attentional abilities post training for the BTA task.

Figure 17 is a display with the raw scores for the three test groups on the NR, a test for which scores may range from 0 to 30.

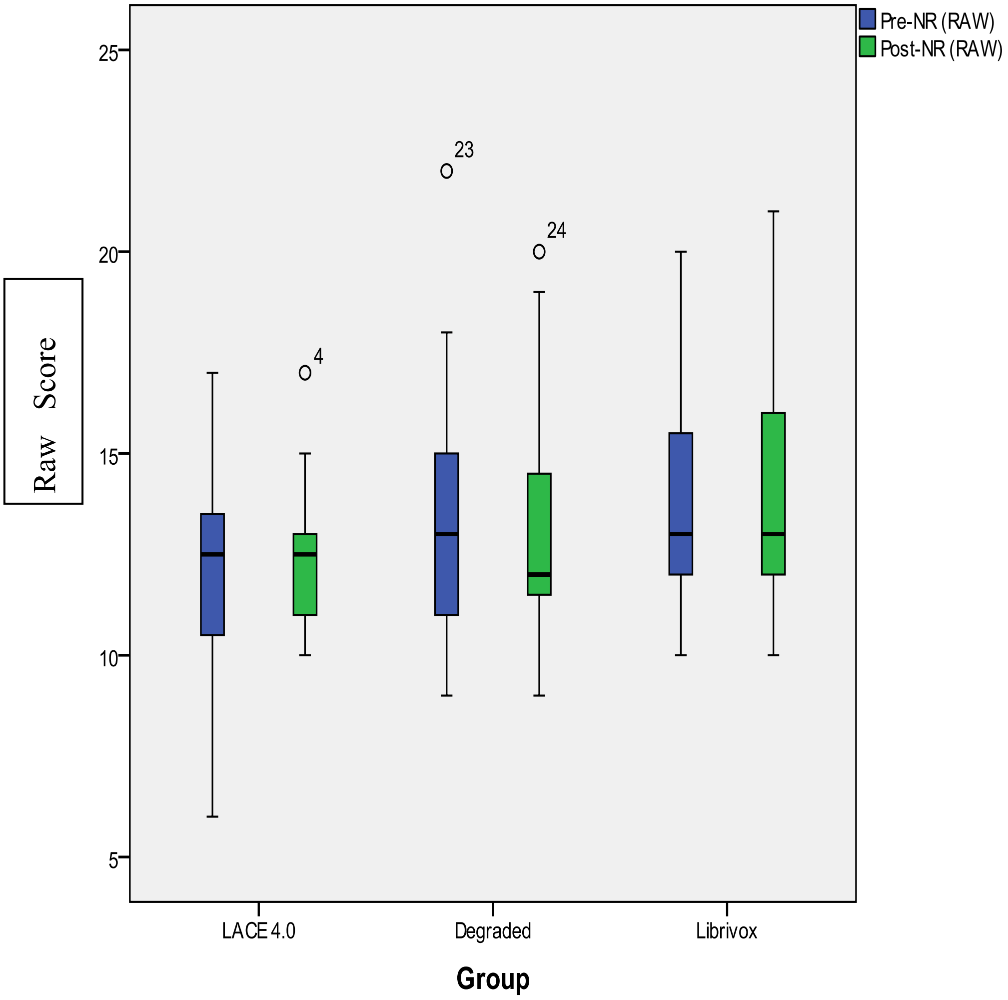

Figure 17: Pre and Post Training Scores for the NR Test for the Three Groups

Pre-NR (RAW) = Raw scores for the Numbers Reversed test prior to listening training; Post-NR (RAW) = Raw scores for the Numbers Reversed test following listening training; numbers 4, 23 and 24 near the outlier markers reflect the case numbers from the database

There was no change in the median scores post training on the NR test for the LACE 4.0 and Librivox group and a slight decrease in the median score for the Degraded group.

Figure 18 is a display with time completion in milliseconds for the ARTT, which in this population ranged up to 2100 milliseconds. Prior to graphing, two outliers were removed; therefore the graph displays ARTT completion times up to approximately 300 milliseconds.

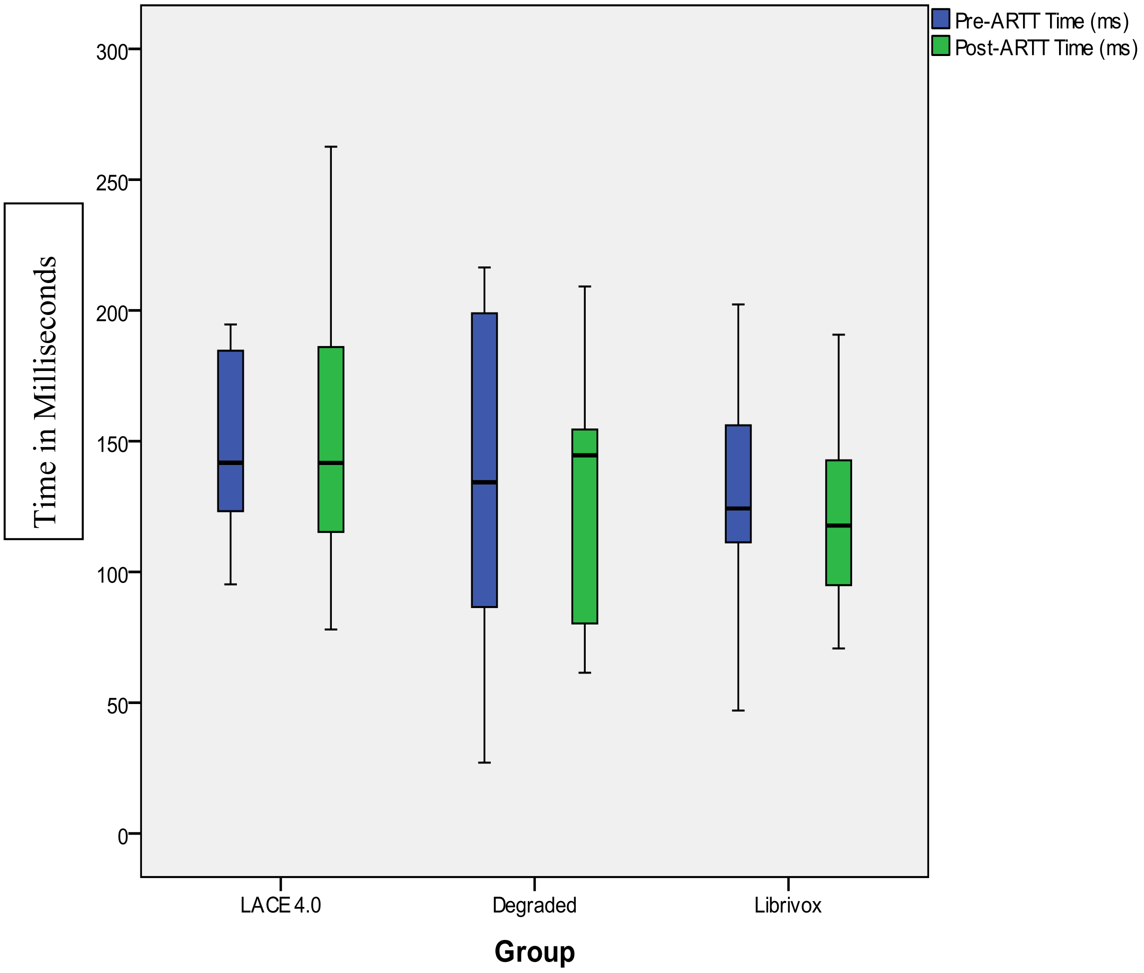

Figure 18: Pre and Post Training Scores for the ARTT Time in Milliseconds for the Three Groups

Pre-AR Time (ms) = Time scores in milliseconds for the Auditory Choice Reaction Time test prior to listening training; Post-AR Time (ms) = Time scores in milliseconds for the Auditory Choice Reaction Time test following listening training; one pre training extreme outlier score (*1, time ~ 2100 ms) from the LACE 4.0 group and one pre training extreme outlier score (* 13, time ~ 700 ms) were excluded from the graph to allow for a better visualization of the pre to post training changes; these two outliers represent individuals who 1) performed this task very slowly (time 2100 ms) and 2) was pressing the keys too lightly for her initial response to register (time 700 ms)

This figure reflects completion time on the ARTT task and a lower time reflects possible improvement. There are lower median scores for completion time post training for the LACE 4.0 and Librivox groups.

Figure 19 is a display with the raw scores for the three test groups on the ARTT accuracy task, a test on which scores may range from 0 to 30.

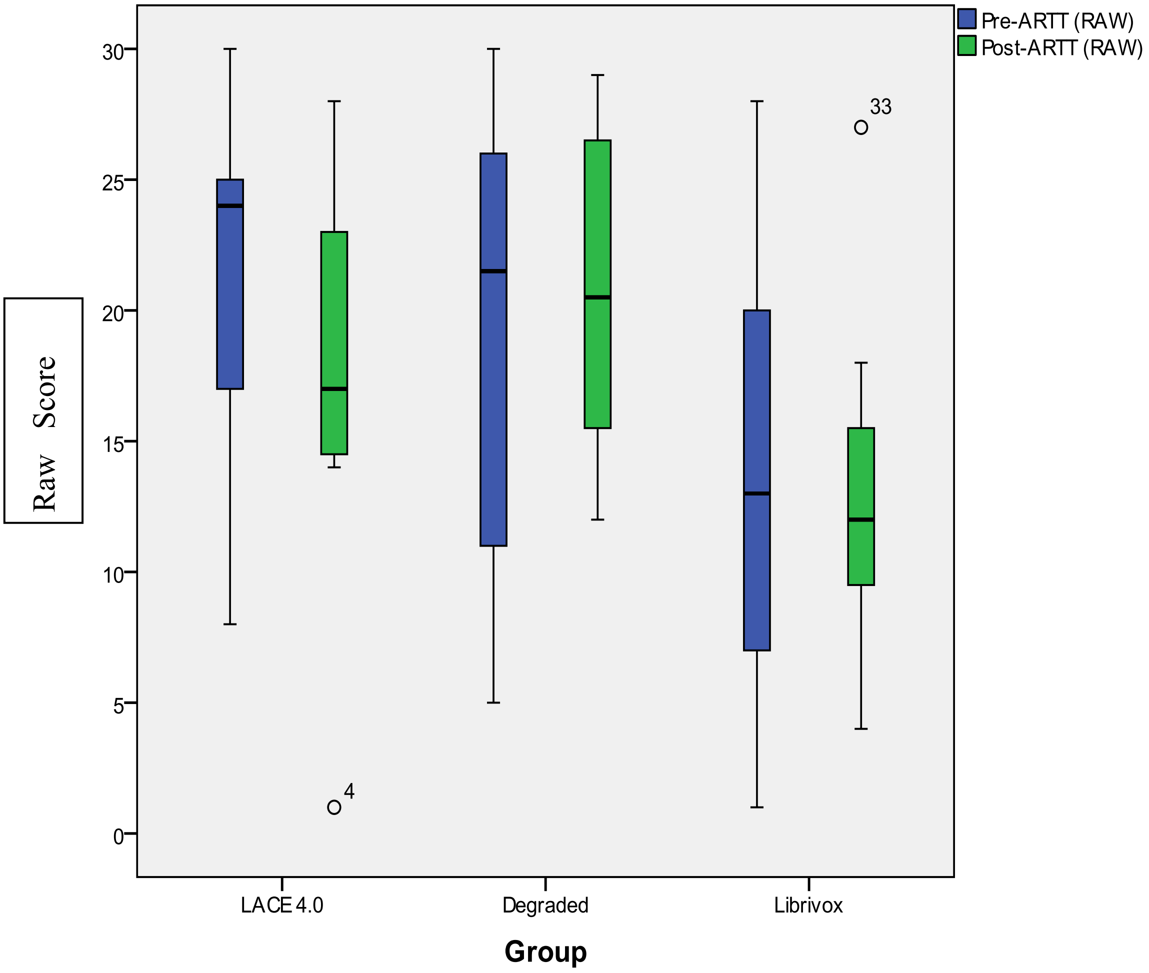

Figure 19: Pre and Post Training Scores for the ARTT Task for the Three Groups

Pre-AR (RAW) = Raw scores for the Auditory Choice Reaction Time test prior to listening training; Post-AR (RAW) = Raw scores for the Auditory Choice Reaction Time test following listening training; the numbers 4 and 33 near the outlier marker reflects the case number from the database

The median scores are lower for ARTT response accuracy post training for all three groups.

Research Question 1: Are there significant changes on test measures following training?

MANOVAs to Explore for Changes in Cognitive Processing Measures.

Three MANOVAs were run to examine possible pre to post training differences in cognitive measures as measured by attention, working memory and processing speed for the test groups. As stated above, the criteria level for significance was relaxed to $p<0.10$; whereas the significance level for examining individual tests was maintained at $p<0.05$.

For the LACE 4.0 Group, Hotelling's Trace statistic was not significant ($p = .760$). The full MANOVA for the LACE 4.0 group is found in Appendix O.

For the LACE-Degraded group, results from the MANOVA using Hotelling's Trace statistics revealed a statistically significant pre-post training difference in cognitive processing ($p = .059$). However, there were no significant differences on any of the cognitive measures at the $p<0.05$ level. The full MANOVA and Test of Between-Subjects Effects are found in Appendix P and Q, respectively.

For the Librivox group, the Hotelling's Trace statistic was not significant ($p = .312$). The full MANOVA for the Librivox group is found in Appendix R.

MANOVAs to Explore Change Scores in Cognitive Processing Measures Between Groups.

A MANOVA was run to examine the change scores following training for possible significant differences in cognitive processing measures as measured by attention, working memory and processing speed between groups. The Hotelling's Trace statistic was not significant ($p = .439$) for changes post-training in cognitive processing between groups. The full MANOVA is found in Appendix S.

Descriptive Statistics for the Self Report Measures

Self-report communication measures included the following: Communication Profile for the Hearing Impaired (CPHI; individual scales are found in Table 5 & 6) (Erdman & Demorest, 1998), Speech Intelligibility Rating Test (SIR) (Cox & McDaniel, 1989) and the Communication Confidence Profile (CCP) (Sweetow & Henderson Sabes, 2010).

Tables 5 and 6 display the descriptive statistics for the pre and post training scores for the self-report communication measures (CPHI, SIR and CCP) for all three groups. Please note that there is incomplete data on the SIR test with only 11 people completing the test in the LACE 4.0 and LACE-Degraded groups and only 10 completing the test in the Librivox group. Figures 20 – 27 are box plots graphically displaying the pre and post training scores on the self-report measures for each group.

Table 5: Means, Standard Deviations and Ranges for Pre and Post Training Scores on the Self-Report Measures (CPHI-Average, Adverse, Verbal and Non-Verbal) Scales for all Three Groups

Self-Report Test Measures	**N**	**Group**	**Mean (Std. Dev) Pre**	**Post**	**Range Pre**	**Post**
Communication Profile for the Hearing Impaired (CPHI) Average	12	LACE 4.0	3.92 (0.59)	4.13 (0.66)	2.9 -5.0	2.7-5.0
	12	Degraded	4.00 (0.66)	4.06 (0.64)	2.7-4.9	2.5-4.9
	11	Librivox	4.15 (0.46)	4.06 (0.39)	3.2-4.7	3.6-4.6
Communication Profile for the Hearing Impaired (CPHI) Adverse	12	LACE 4.0	3.27 (0.69)	3.23 (0.69)	2.3-4.9	2.4-5.0
	12	Degraded	3.21 (0.61)	3.42 (0.62)	2.4-4.1	2.3-4.3
	11	Librivox	3.21 (0.56)	3.20 (0.65)	1.9-4.0	2.1-3.9
Communication Profile for the Hearing Impaired (CPHI) Verbal	12	LACE 4.0	2.50 (0.80)	2.43 (0.82)	1.4-4.0	1.1-3.5
	12	Degraded	2.25 (0.67)	2.42 (0.61)	1.0-3.4	1.0-3.0
	11	Librivox	3.07 (0.77)	3.03 (0.94)	1.9-4.1	1.9-5.0
Communication Profile for the Hearing Impaired (CPHI) Non-Verbal	12	LACE 4.0	3.38 (0.80)	3.47 (0.77)	2.4-4.8	2.6-4.8
	12	Degraded	3.71 (0.91)	3.57 (0.86)	2.0-4.8	2.3-5.0
	11	Librivox	3.58 (1.12)	3.60 (0.95)	1.6-5.0	2.0-4.8

Table 6: Means, Standard Deviations and Ranges for Pre and Post Training Scores on the Self-Report Measures (CPHI –Discouragement and Stress Scales), SIR and CCP for all Three Groups

Self-Report Test Measures	**N**	**Group**	**Mean (Std. Dev) Pre**	**Post**	**Range Pre**	**Post**
Communication Profile for the Hearing Impaired (CPHI) Discouragement	12	LACE 4.0	3.61 (0.87)	3.96 (0.61)	2.3-5.0	3.0-4.8
	12	Degraded	3.86 (0.91)	3.89 (0.93)	1.5-5.0	1.7-4.8
	11	Librivox	3.90 (0.51)	4.17 (0.50)	3.2-4.5	3.2-4.8
Communication Profile for the Hearing Impaired (CPHI) Stress	12	LACE 4.0	3.62 (0.98)	3.72 (0.81)	2.0-5.0	2.1-4.9
	12	Degraded	3.50 (0.89)	3.63 (0.91)	2.0-5.0	1.7-4.8
	11	Librivox	3.46 (0.72)	3.68 (0.62)	2.1-4.6	2.9-4.9
Speech Intelligibility Rating Test (SIR)	11	LACE 4.0	6.85 (2.24)	7.38 (2.43)	2.9-9.25	1.2-9.75
	11	Degraded	7.61 (1.80)	7.29 (1.69)	3.4-9.4	4.3-9.8
	10	Librivox	6.85 (1.66)	5.69 (2.49)	2.9-8.9	1.9-9.9
Communication Confidence Profile (CCP)	12	LACE 4.0	37.83 (6.19)	39.17 (4.82)	27-50	31-49
	12	Degraded	36.67 (5.16)	36.58 (4.25)	29-45	29-42
	11	Librivox	39.82 (5.79)	37.82 (6.16)	30-52	27-48

Figure 20 is a display with the average scores for the three test groups on the CPHI-Average Scale, a scale on which scores may range from 0 to 5.

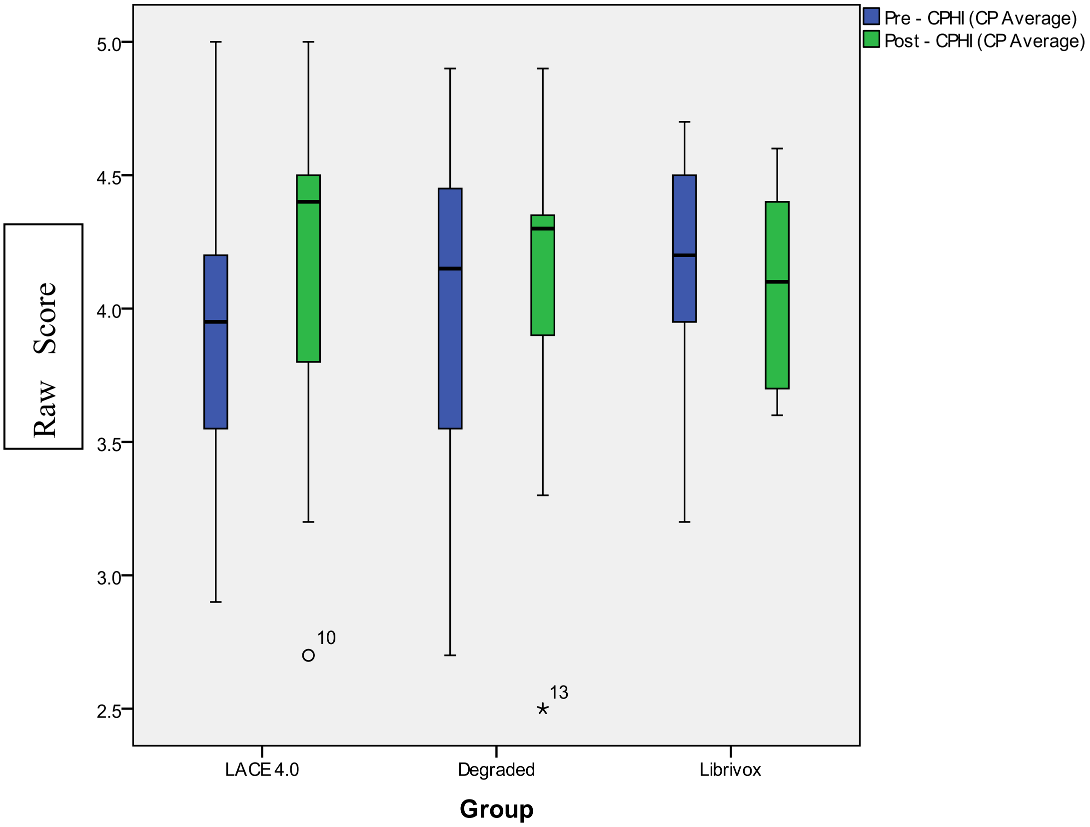

Figure 20: Pre and Post Training Scores for the CPHI-Average Scale for the Three Groups

Pre-CPHI (CP Average) = Average scores on the Communication Profile for the Hearing Impaired for the Communication Performance Average Scale prior to listening training; Post-CPHI (CP Average) = Average scores on the Communication Profile for the Hearing Impaired for the Communication Performance Average Scale following listening training; numbers 10 and 13 near the outlier markers reflect the case numbers from the database; *13 = extreme outlier

High scores for this scale reflect “effective communication or good adjustment” to hearing loss in average listening conditions; while low scores reflect possible “communication or adjustment difficulties” (Erdman, 2007 p. 3). The post training median scores are higher relative to perceived effective communication and/or better adjustment to hearing loss for the LACE 4.0 and LACE Degraded groups.

Figure 21 is a display with the average scores for the three test groups on the CPHI-Adverse Scale, a scale on which scores may range from 0 to 5.

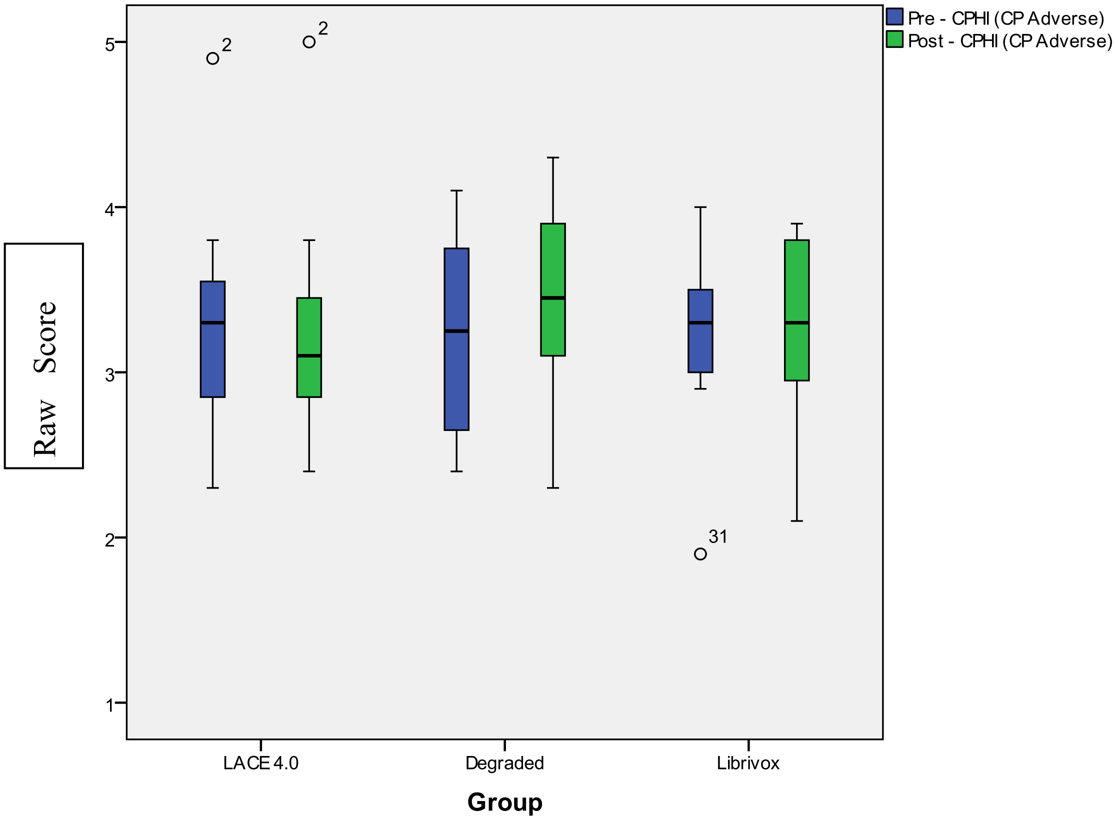

Figure 21: Pre and Post Training Scores for the CPHI-Adverse Scale for the Three Groups Pre-CPHI (CP Adverse) = Average scores on the Communication Profile for the Hearing Impaired for the Communication Performance Adverse Scale prior to listening training; Post-CPHI (CP Adverse) = Average scores for the Communication Profile for the Hearing Impaired for the Communication Performance Adverse Scale following listening training; numbers 2 and 31 near the outlier markers reflect the case numbers from the database

High scores for this scale reflect “effective communication or good adjustment” to hearing loss in adverse or difficult listening situations; while low scores reflect possible “communication or adjustment difficulties” (Erdman, 2007 p. 3). The post training median scores are higher reflecting more effective communication and/or better adjustment to hearing loss for the LACE Degraded group.

Figure 22 is a display with the average scores for the three test groups on the CPHI-Verbal Scale, a scale on which scores may range from 0 to 5.

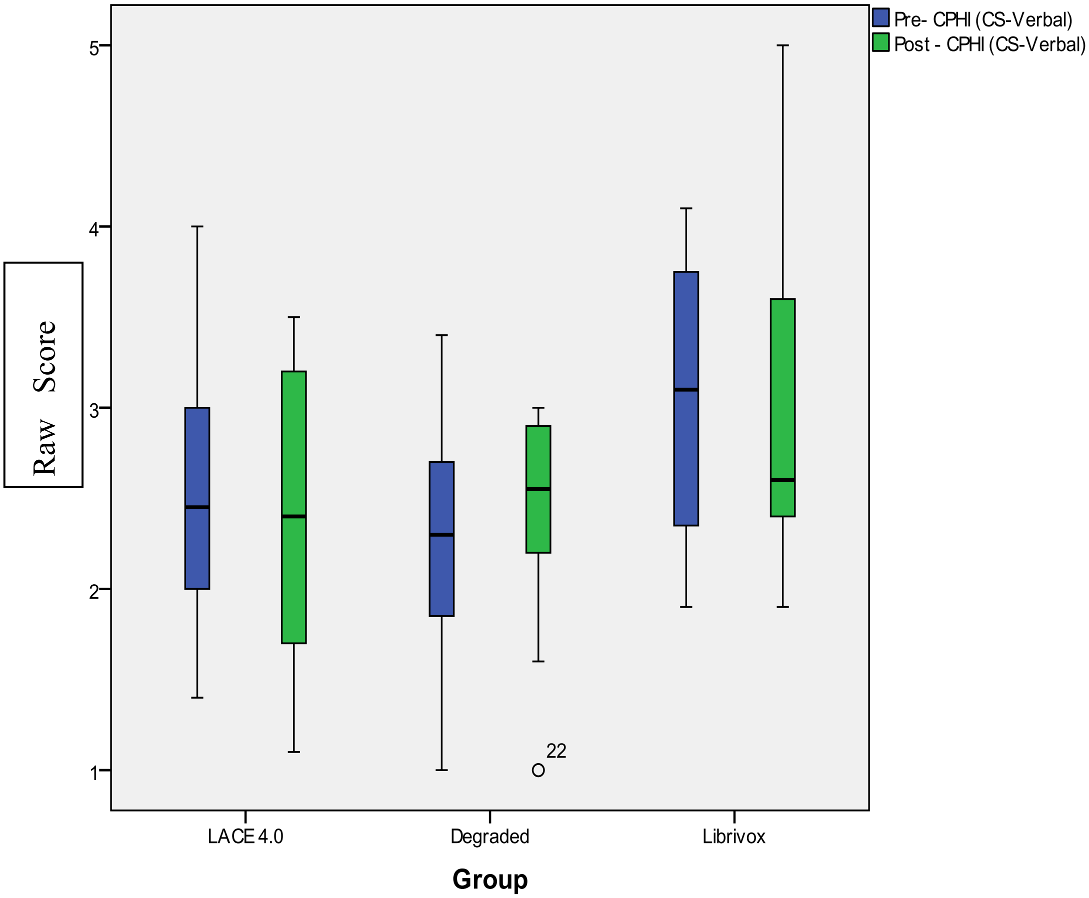

Figure 22: Pre and Post Training Scores for the CPHI-Verbal Scale for the Three Groups

Pre-CPHI (CS Verbal) = Average scores on the Communication Profile for the Hearing Impaired for the Communication Strategies Verbal Strategies Scale prior to listening training; Post-CPHI (CS Verbal) = Average scores on the Communication Profile for the Hearing Impaired for the Communication Strategies Verbal Strategies Scale following listening training; number 22 near the outlier marker reflects the case number from the database

The Verbal Scale assesses the frequency with which verbal strategies are used in order to reduce difficulties hearing. For the LACE-Degraded group, the post training median scores are higher reflecting increased use of verbal strategies.

Figure 23 is a display with the average scores for the three test groups on the CPHI-Non-Verbal Scale, a scale on which scores may range from 0 to 5.

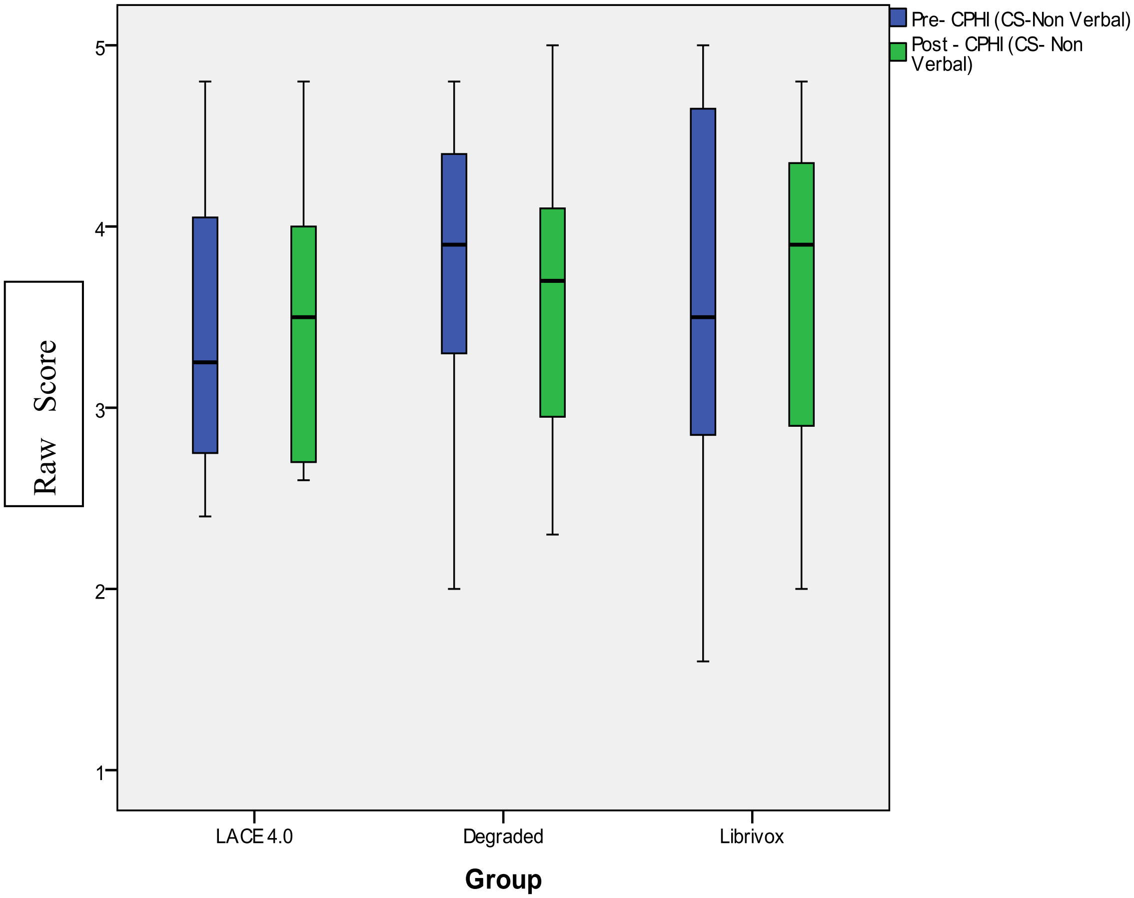

Figure 23: Pre and Post Training Scores for the CPHI-Non-Verbal Scale for the Three Groups

Pre-CPHI (CS Non-Verbal) = Average scores on the Communication Profile for the Hearing Impaired for the Communication Strategies Non-Verbal Strategies Scale prior to listening training; Post-CPHI (CS Non-Verbal) = Average scores on the Communication Profile for the Hearing Impaired for the Communication Strategies Non-Verbal Strategies Scale following listening training

The Non-Verbal Scale assesses how often “effective behaviors” or strategies are used to reduce difficulties hearing (Erdman, 2006, p. 7). High scores reflect more frequent use of non-verbal strategies. For the LACE 4.0 and Librivox groups, the post training median scores are higher; reflecting more frequent use of non-verbal strategies.

Figure 24 is a display with the average scores for the three test groups on the CPHI-Discouragement Scale, a scale on which scores may range from 0 to 5.

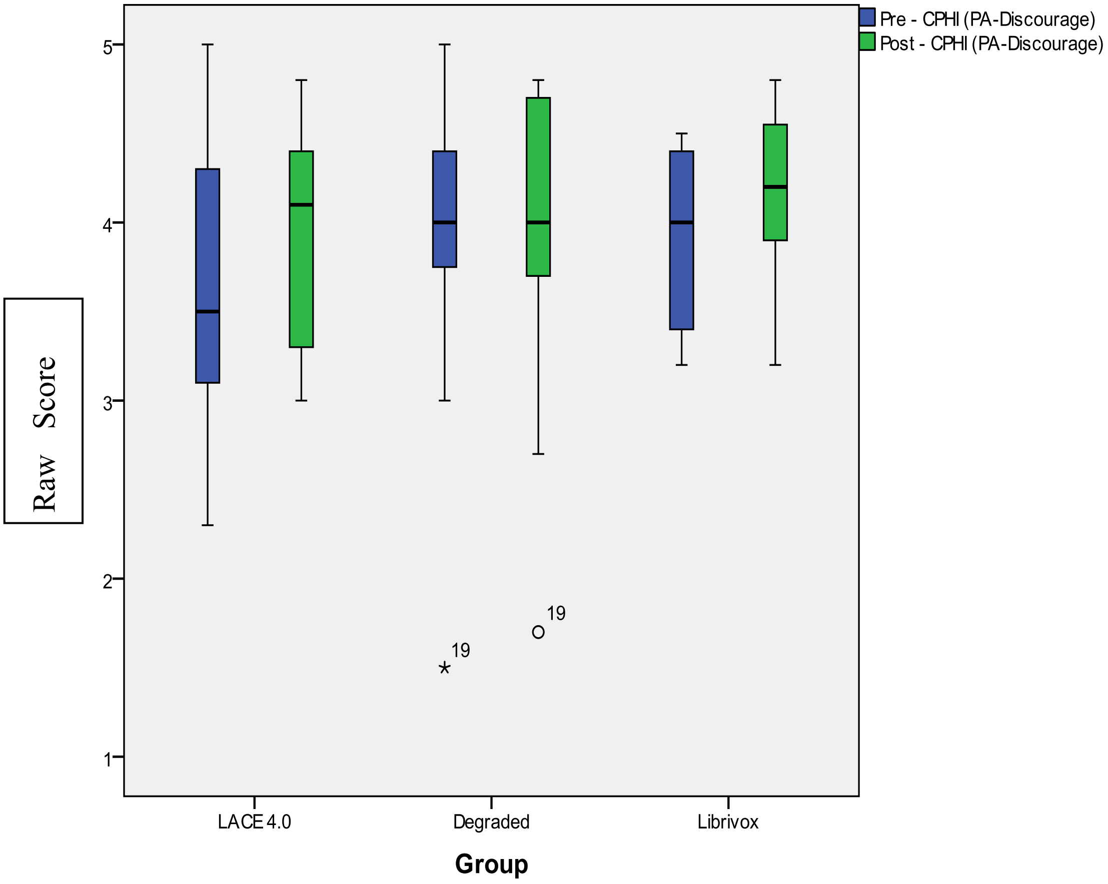

Figure 24: Pre and Post Training Scores for the CPHI-Discouragement Scale for the Three Groups

Pre-CPHI (PA-Discourage) = Average scores on the Communication Profile for the Hearing Impaired for the Personal Adjustment Discouragement Scale prior to listening training; Post-CPHI (PA-Discourage) = Average scores on the Communication Profile for the Hearing Impaired for the Personal Adjustment Discouragement Scale following listening training; number 19 near the outlier markers reflect the case number from the database; *19 = extreme outlier

High scores for the CPHI-Discouragement Scale reflect limited feelings of discouragement relative to communication difficulties as a result of hearing loss; while low scores reflect “a general feeling of discouragement” relative to communication difficulties as a result of hearing loss (Erdman, 2007, p. 9). For the LACE 4.0 and Librivox groups, the post training median scores are higher reflecting reduced feelings of discouragement (i.e., higher scores).

Figure 25 is a display with the average scores for the three test groups on the CPHI-Stress Scale, a scale on which scores may range from 0 to 5.

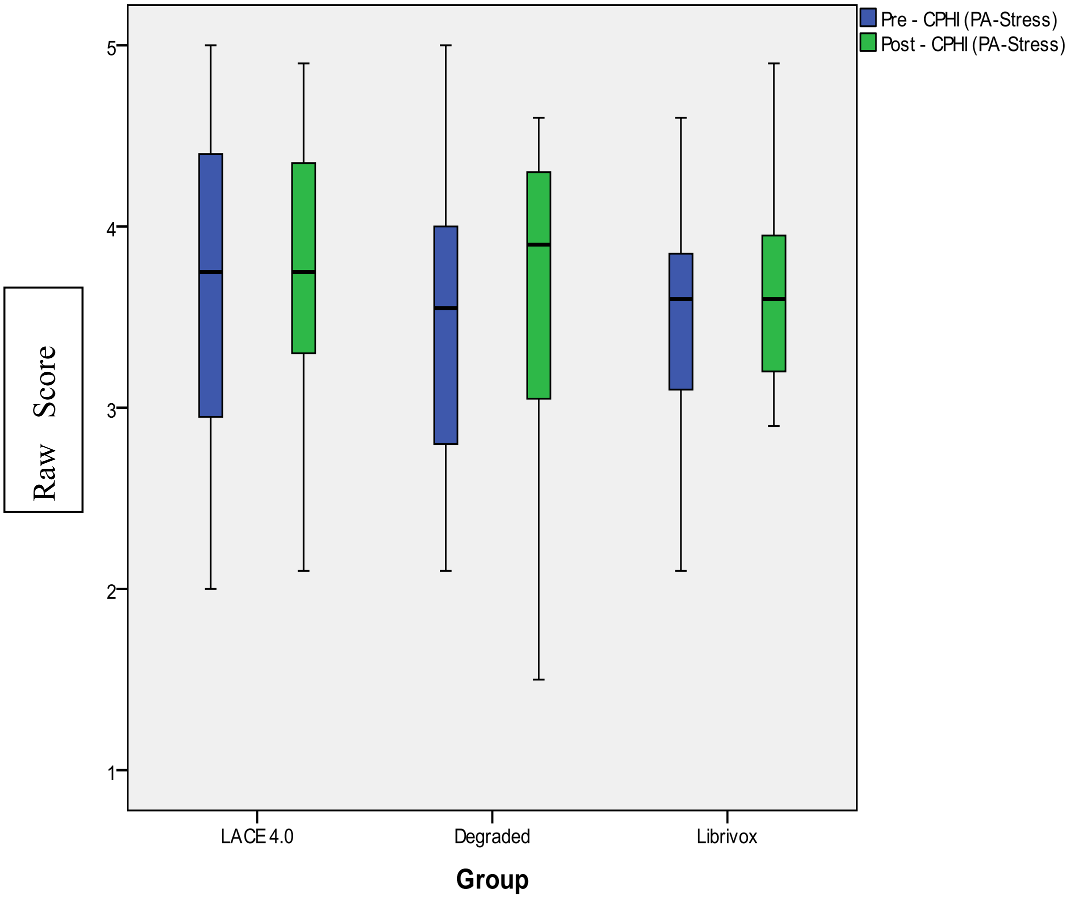

Figure 25: Pre and Post Training Scores for the CPHI-Stress Scale for the Three Groups

Pre-CPHI (PA-Stress) = Average scores on the Communication Profile for the Hearing Impaired for the Personal Adjustment Stress Scale prior to listening training; Post-CPHI (PA-Stress) = Average scores on the Communication Profile for the Hearing Impaired for the Personal Adjustment Stress Scale following listening training

High scores for this scale reflect improved personal adjustment to hearing impairment or minimal stress; while low scores reflect poor personal adjustment. For the LACE 4.0 and LACE-Degraded groups, the post training median scores are higher reflecting decreased stress.

Figure 26 is a display with the raw scores for the three test groups on the SIR, a test on which scores may range from 0 to 10.

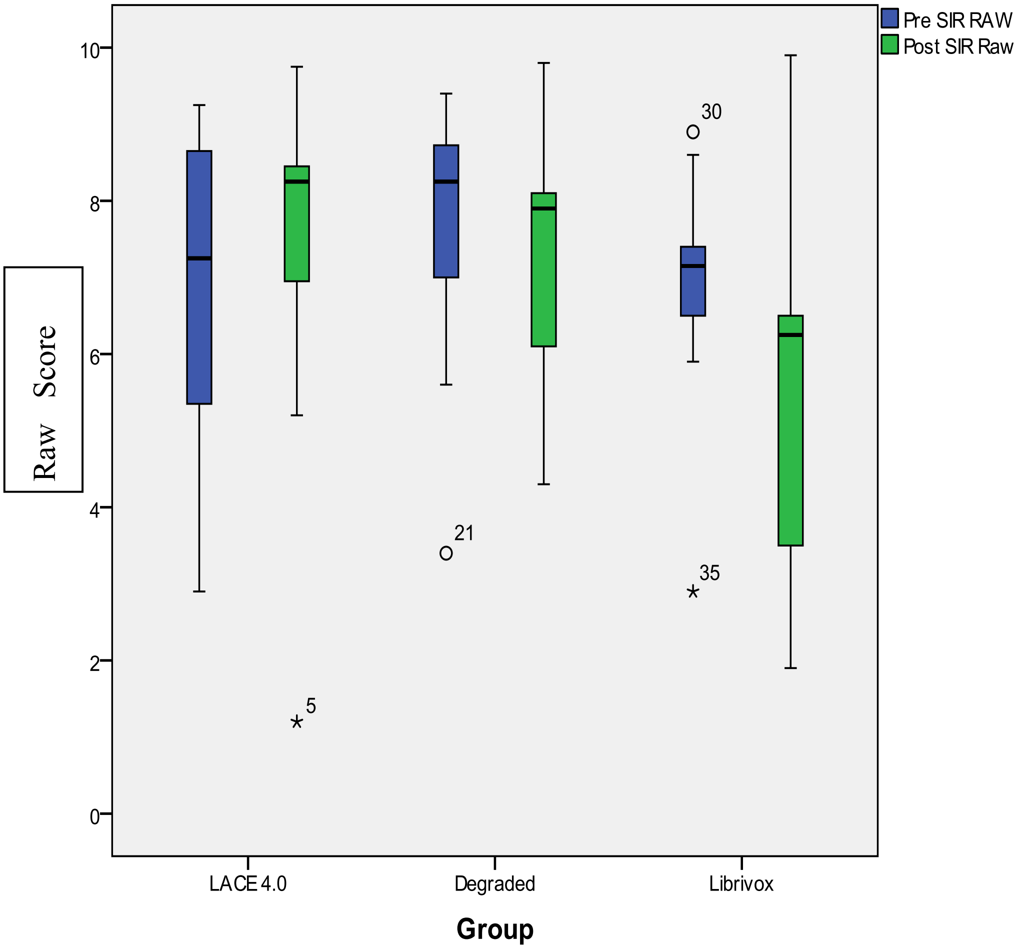

Figure 26: Pre and Post Training Scores for the SIR Test for the Three Groups

Pre-SIR RAW = Raw scores for the Speech Intelligibility Rating test prior to listening training; Post-SIR RAW = Raw scores for the Speech Intelligibility Rating test following listening training; numbers 5, 21, 30 and 35 near the outlier markers reflect the case numbers from the database; *5 and *35 = extreme outliers

The SIR score represents the number of words from a given topic-based passage that a participant judges they were able to correctly identify. For the LACE 4.0 group, the post training median score is higher reflecting an increase in the proportion of words reportedly understood.

Figure 27 is a display with the raw scores for the three test groups on the CCP, a test on which scores may range from 0 to 60.

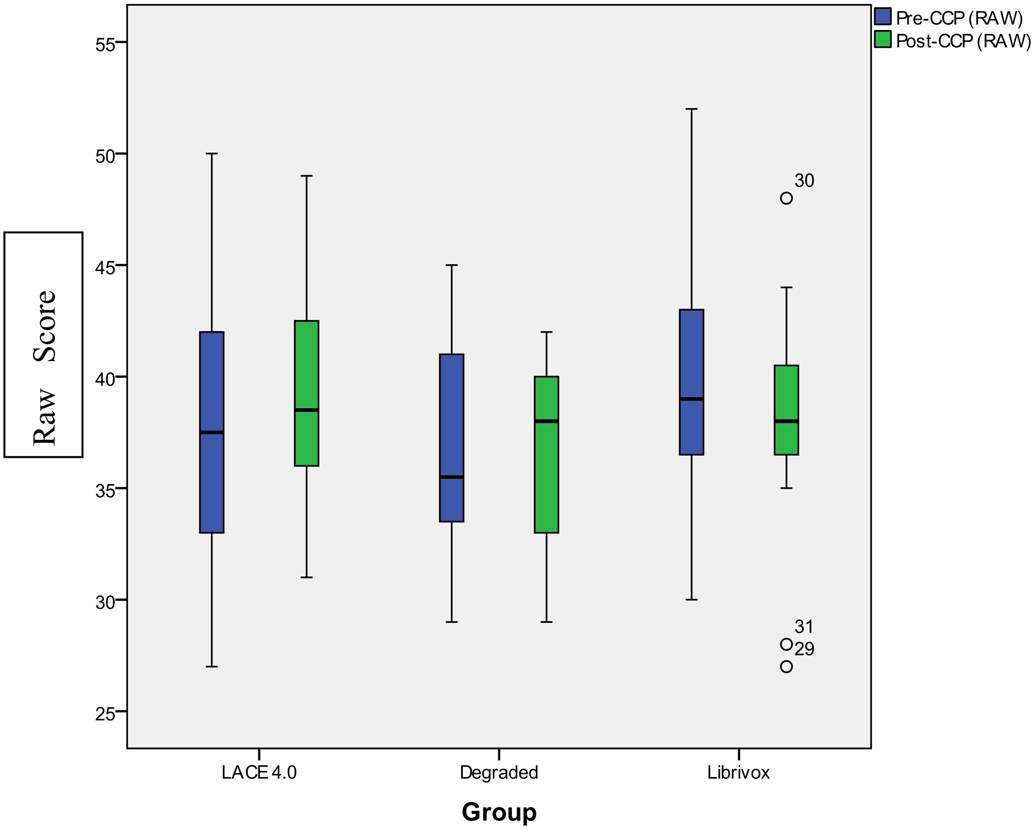

Figure 27: Pre and Post Training Scores for the CCP for the Three Groups

Pre-CCP (RAW) = Raw scores for the Communication Confidence Profile test prior to listening training; Post-CCP (RAW) = Raw scores for the Communication Confidence Profile test following listening training; numbers 29, 30 and 31 near the outlier markers reflect the case numbers from the database

Improved scores indicate higher communication confidence. For the LACE 4.0 and LACE-Degraded groups, the post training median scores are higher reflecting improved communication confidence.

Research Question 1: Are there significant changes on test measures following training?

MANOVAs to Explore for Changes in Self-report Measures

Three separate MANOVAs were run to examine pre to post training differences on self-report communication measures as measured by ratings of self-perceived function in average and adverse listening conditions, use of verbal and non-verbal strategies as well as discouragement and stress related to hearing difficulties, judgment of proportion of words understood in a passage and self-perceived communication confidence for the test groups.

For the LACE 4.0 group, the Hotellings Trace statistic for the self-report measures revealed a borderline statistically significant pre-post difference (p=.102). This borderline result was considered significant as this study was exploratory in nature. In addition, some of the individual self-report measures were found to be significantly different at p<.05, thus warranting further examination. Specifically, statistically significant pre-post training differences for self-reports were found for the following tests: CPHI Discouragement Scale (p = .003), and the CPHI Adverse Scale (p = .015). The full MANOVA and Tests of Between-Subjects Effects for the LACE 4.0 group are found in Appendix T and U, respectively.

For the LACE-Degraded group no significant changes were found (p=.130). The full MANOVA for the LACE-Degraded group is in Appendix V.

For the Librivox group, no significant changes were found (p=.929). The full MANOVA for the Librivox group is found in Appendix W.

MANOVAs to Explore Change Scores in Self Report Measures Between Groups

A MANOVA was run to examine the change scores following training for possible significant differences in self-report measures as measured by ratings of self-perceived function in average and adverse listening conditions, use of verbal and non-verbal strategies as well as discouragement and stress related to hearing difficulties, judgment of proportion of words understood in a passage and self-perceived communication confidence between groups. The Hotelling's Trace statistic was not significant ($p = .128$) for changes post-training on the self-report measures between groups. The full MANOVA is found in Appendix X.

Research Question 2: Are there significant correlations between the initial scores on cognitive measures and the changes in speech perception scores, and are there significant correlations between the initial scores on self reports and changes in the speech perception scores?

Other researchers (Henderson Sabes & Sweetow, 2007) have questioned whether performance on any one or any set of measures might be associated with improvement in speech perception following auditory training. If such a characteristic were identified, then those with that characteristic might be better prospects for training. Difference scores between pre and post training speech perceptual measures (WIN, CST, DSI, TC, DDT, and i-CAST) were calculated and correlated with the initial scores on the cognitive measures (BTA, NR, and ARTT) and with initial scores on the self-report measures (CPHI, SIR, and CCP). Pearson Product Moment correlation results are presented below in Table 7.

Table 7: Pearson Product Correlations-Initial Cognitive Measures and Self-Report Measures with Speech Perceptual Change Scores

Speech Measures	Pre BTA	Pre NR	Pre ARTT (Time)	Pre ARTT Task	Pre CPHI Average	Pre CPHI Adverse	Pre CPHI Verbal	Pre CPHI Non-Verbal	Pre CPHI Discrg	Pre CPHI Stress	Pre SIR	Pre CCP
P-P WIN	.078	-.240	.042	-.041	.005	.256	-.409*	-.030	-.083	.098	.050	-.180
P-P CST	.409*	-.014	-.403*	-.532**	.171	.258	-.074	.025	.021	.133	.007	.138
P-P DSI RT	.032	-.008	-.284	-.224	.078	.011	-.101	-.020	.089	.273	.183	-.018
P-P DSI LT	-.125	-.233	-.052	.043	-.142	.112	-.287	-.254	-.130	-.066	.143	-.056
P-P TC	.254	.107	-.079	-.259	.067	.100	.015	.021	.077	.274	.079	-.191
P-P DDT FR RT	-.025	.222	-.171	.002	-.102	-.200	.286	.082	-.045	.116	.168	.124
P-P DDT FR LT	-.082	-.321	.006	-.165	.031	.005	-.180	.023	.014	-.083	.077	-.154
P-P DDT DR RT	-.079	.371*	.071	.006	.013	-.197	.251	.249	.013	-.193	.073	.077
P-P DDT DR LT	-.060	.084	.093	.239	-.162	-.056	-.081	.099	.169	.004	.074	-.123
P-P i-CAST (Time)	.285	.066	-.041	.046	-.169	-.108	-.185	-.113	-.044	-.136	-.193	-.063
P-P i-CAST Syllable	.124	.045	-.120	-.081	-.169	-.087	-.049	-.001	.213	.209	.548**	-.020

Note: * Significance at .05 (2-Tailed); ** Significance at .01 (2-Tailed);
P-P WIN=Pre-Post Words in Noise; P-P CST=Pre-Post Connected Speech Test; P-P DSI RT=Pre-Post Dichotic Sentence Identification Right Ear; P-P DSI LT=Pre-Post Dichotic Sentence Identification Left Ear; P-P TC=Pre-Post Time Compressed Speech; P-P DDT FR RT=Pre-Post Dichotic Digits Triplets Free-Recall Right Ear; P-P DDT FR LT=Pre-Post Dichotic Digits Triplets Free-Recall Left Ear; P-P DDT DR RT=Pre-Post Dichotic Digits Triplets Directed-Recall Right Ear; P-P DDT DR LT=Pre-Post Dichotic Digits Triplets Directed-Recall Left Ear; P-P i-CAST (Time)=Pre-Post Internet-Based Computer Assisted Training Time in Minutes Condition; P-P i-CAST Syllable=Pre-Post Internet-Based Computer Assisted Training Syllable Identification Task; Pre BTA=Pre Brief Test of Attention; Pre NR= Pre Numbers Reversed; Pre ARTT (Time)=Pre Auditory Choice Reaction Time Test Time in Milliseconds Condition; Pre ARTT Task=Pre Auditory Choice Reaction Time Test Time Task; Pre CPHI Average=Pre Communication Profile for the Hearing Impaired Average Scale; CPHI Adverse=Pre Communication Profile for the Hearing Impaired Adverse Scale; CPHI Verbal=Pre Communication Profile for the Hearing Impaired Verbal Scale; CPHI Non-Verbal=Pre Communication Profile for the Hearing Impaired Non-Verbal Scale; CPHI Discrg=Pre Communication Profile for the Hearing Impaired Discouragement Scale; CPHI Stress=Pre Communication Profile for the Hearing Impaired Stress Scale; Pre SIR=Pre Speech Intelligibility Rating; Pre CCP=Pre Communication Confidence Profile

Only a few statistically significant correlations were found ($p<0.05$) between the speech perceptual change scores and the initial measures of cognitive processing and self-report measures, with the exact correlation value found in table 7. Small to moderate statistically significant positive correlations were found between the following: CST difference score and BTA; DDT right ear difference score and NR; and i-CAST Syllable difference score and SIR. Small to moderate negative correlations were found between the following: WIN difference score and CPHI V; CST difference score and ARTT Time; and CST difference score and ARTT Task. In summary, changes in speech perceptual measures were not highly correlated with initial cognitive or self-report measures, but did show some small to moderate significant correlations.

Research Question 3: Are there significant correlations between self-report measures?

Pearson Product Moment Correlation analyses were run on the pre-training scores for the self-report communication measures (CPHI, SIR, and CCP) to establish whether these measures were examining the same or different aspects of self-reported communication. Correlations of interest were those between the CPHI Scales and the SIR and the CCP. The correlation results are presented below in Table 8.

Table 8: Pearson Product Correlations-Self Report Measures

Self-Report Measures	**Pre CPHI Average**	**Pre CPHI Adverse**	**Pre CPHI Verbal**	**Pre CPHI Non-Verbal**	**Pre CPHI Discrg**	**Pre CPHI Stress**	**Pre SIR**	**Pre CCP**
Pre CPHI Average								
Pre CPHI Adverse	.560**							
Pre CPHI Verbal	-.004	-.283						
Pre CPHI Non-Verbal	.093	.017	.553**					
Pre CPHI Discouragement	.456**	.264	-.284	-.215				
Pre CPHI Stress	.239	.374*	-.334	-.393*	.690**			
Pre SIR	**.156**	**-.023**	**.118**	**.120**	**.325**	**.272**		
Pre CCP	**.415***	**.368***	**.290**	**.142**	**.339***	**.264**	**.142**	

Note: * Significance at .05 (2-Tailed); ** Significance at .01 (2-Tailed);
Bold cells reflect correlations of interest

Pre CPHI Average= Pre Communication Profile for the Hearing Impaired Average Scale; Pre CPHI Adverse= Pre Communication Profile for the Hearing Impaired Adverse Scale; Pre CPHI Verbal= Pre Communication Profile for the Hearing Impaired Verbal Scale; Pre CPHI Non-Verbal= Pre Communication Profile for the Hearing Impaired Non-Verbal Scale;
Pre CPHI Discrg= Pre Communication Profile for the Hearing Impaired Discouragement Scale;
Pre CPHI Stress= Pre Communication Profile for the Hearing Impaired Stress Scale;
Pre SIR=Pre Speech Intelligibility Rating;
Pre CCP= Pre Communication Confidence Profile

Small to moderate statistically significant positive correlations were found between the following tests: CPHI Average Scale and CCP; CPHI Adverse Scale and CCP; and CPHI Discouragement Scale and CCP. Based on the small to moderate positive correlations revealed during this analysis, results suggest that these tests may be examining different aspects of self-reported communication.

Research Question 4: Are there significant correlations between the speech perceptual measures?

Pearson Product Moment Correlation analyses were run on the pre-training scores for the speech perceptual measures (WIN, CST, DSI, TC, DDT, and i-CAST) to examine possible associations between speech perceptual test measures. A finding of a strong correlation between measures could be grounds for removing one or more measures and shortening the test battery. The correlation results are presented below in Table 9.

Table 9: Pearson Product Correlations-Speech Perceptual Measures

Speech Measures	Pre WIN	Pre CST	Pre DSI RT	Pre DSI LT	Pre TC	Pre DDT FR RT	Pre DDT FR LT	Pre DDT DR RT	Pre DDT DR LT	Pre i-CAST Time	Pre i-CAST Syllable
Pre WIN											
Pre CST	__.072__										
Pre DSI RT	__.346*__	__.180__									
Pre DSI LT	__.135__	__.278__	.546**								
Pre TC	__.767**__	__.207__	__.252__	__-.090__							
Pre DDT FR RT	__.040__	__.060__	__.242__	__.140__	__-.131__						
Pre DDT FR LT	__.145__	__.121__	__.025__	__.457**__	__-.118__	.131					
Pre DDT DR RT	__.190__	__.002__	__.360*__	__.225__	__.040__	__.590**__	__.418*__				
Pre DDT DR LT	__.176__	__.170__	__.120__	__.263__	__.173__	__-.067__	__.563**__	.370*			
Pre i-CAST Time	__-.348*__	__-.226__	__-.308__	__-.194__	__-.242__	__-.116__	__-.185__	__-.318__	__.079__		
Pre i-CAST Syllable	__.461**__	__-.114__	__.408*__	__.425*__	__.282__	__.188__	__.207__	__.322__	__.058__	-.421*	

Note: * Significance at .05 (2-Tailed); ** Significance at .01 (2-Tailed);
Bold cells are correlations of interest

Pre WIN=Pre Words in Noise; Pre CST=Pre Connected Speech Test; Pre DSI RT=Pre Dichotic Sentence Identification Right Ear; Pre DSI LT=Pre Dichotic Sentence Identification Left Ear; Pre TC=Pre Time Compressed Speech; Pre DDT FR RT=Pre Dichotic Digits Triplets Free-Recall Right Ear; Pre DDT FR LT=Pre Dichotic Digits Triplets Free-Recall Left Ear; Pre DDT DR RT=Pre Dichotic Digits Triplets Directed-Recall Right Ear; Pre DDT DR LT=Pre Dichotic Digits Triplets Directed-Recall Left Ear; Pre i-CAST (Time)=Pre Internet-Based Computer Assisted Training Time in Minutes Condition; Pre i-CAST Syllable=Pre Internet-Based Computer Assisted Training Syllable Identification Task

All correlations discussed can be found in table 9. One strong significant correlation was found between two speech perceptual measures. The statistically significant strong positive correlation was between: WIN and TC. Small to moderate statistically significant positive correlations were found between: WIN and DSI right ear; WIN and i-CAST syllable identification; DSI right ear and DSI left ear; DSI right ear and i-CAST syllable identification; DSI left ear and i-CAST syllable identification; DDT free-recall right ear and DDT directed-recall right ear; DDT free-recall left ear and DSI left ear; DDT free-recall left ear and DDT directed-recall right ear; DDT free-recall left ear and DDT directed-recall left ear; DDT directed-recall right ear and DDT free-recall right ear; DDT directed-recall right ear and DDT directed recall left ear; DDT directed-recall right ear and DSI right ear. In contrast, the CST was the only measure that was not significantly correlated with any other test.

Research Question 5: Are there significant correlations between the processing speed measures?

Pearson Product Moment Correlation analyses were run on the pre-training scores for the processing speed measures (TC, ARTT, and i-CAST) to examine the extent to which these measures are related. Correlation results are presented below in Table 10.

Table 10: Pearson Product Correlations-Processing Speed Measures

Processing Speed Measures	**Pre TC**	**Pre i-CAST Time**	**Pre i-CAST Syllables**	**Pre ARTT Time**	**Pre ARTT Task**
Pre TC					
Pre i-CAST Time	-.242				
Pre i-CAST Syllables	**.282**	-.421*			
Pre ARTT Time	**-.222**	**.127**	**-.082**		
Pre ARTT Task	**.040**	**.086**	**-.118**	.387*	

Note: * Significance at .05 (2-Tailed); ** Significance at .01 (2-Tailed);
Bold cells are correlations of interest

Pre TC=Pre Time Compressed Speech; Pre i-CAST (Time)=Pre Internet-Based Computer Assisted Training Time Condition; Pre i-CAST Syllable=Pre Internet-Based Computer Assisted Training Syllable Identification; Pre ARTT Time=Pre Auditory Choice Reaction Time in Milliseconds; Pre ARTT Task=Pre Auditory Choice Reaction Time Task

Of the five processing speed measures, the Time Compressed Speech test was the only measure that did not have any significant correlations with other measures. All correlation values are presented in table 10. A positive correlation was found between: ARTT time and ARTT task accuracy. In addition, a small to moderate statistically significant negative correlation was found between: i-CAST time and i-CAST syllable identification. Thus, there were significant correlations for measures within the ARTT and i-CAST tests (accuracy and time measures) but no significant correlations between the three different tests (TC, i-CAST, ARTT).

While all of these measures are believed to reflect processing speed, the scores on these tests were not highly correlated, indicating that they may be evaluating different issues or aspects of processing speed.

Research Question 6: Are there significant correlations between cognitive processing measures?

Pearson Product Moment Correlation analyses were run on the pre-training scores for the cognitive processing measures (DDT, BTA, and NR) to determine if performance on these working memory tests were related. The correlation results are presented below in Table 11.

Table 11: Pearson Product Correlations-Cognitive Processing Measures

Working Memory Measures	**Pre DDT FR RT**	**Pre DDT FR LT**	**Pre DDT DR RT**	**Pre DDT DR LT**	**Pre BTA**	**Pre NR**
Pre DDT FR RT						
Pre DDT FR LT	.131					
Pre DDT DR RT	**.590****	**.418***				
Pre DDT DR LT	**-.067**	**.563****	.370*			
Pre BTA	**.387***	**.260**	**.480****	**.228**		
Pre NR	**.112**	**.430****	**.337***	**.249**	**.293**	

Note: * Significance at .05 (2-Tailed); ** Significance at .01 (2-Tailed); Bold cells are correlations of interest

Pre DDT FR RT=Pre Dichotic Digits Triplets Free-Recall Right Ear;
Pre DDT FR LT=Pre Dichotic Digits Triplets Free-Recall Left Ear;
Pre DDT DR RT=Pre Dichotic Digits Triplets Directed-Recall Right Ear;
Pre DDT DR LT=Pre Dichotic Digits Triplets Directed-Recall Left Ear;
Pre BTA=Pre Brief Test of Attention;
Pre NR=Pre Numbers Reversed

Small to moderate correlations were found between: DDT free-recall right ear and DDT directed-recall right ear; DDT free-recall right ear and BTA; DDT free-recall left ear and DDT directed-recall right ear; DDT free-recall left ear and DDT directed-recall left ear; DDT free-recall left ear and NR; DDT directed-recall right ear and DDT directed-recall left ear; and DDT directed-recall right ear and BTA. These correlation values are presented in table 11. Once again the correlations were not strong, suggesting that these tests may be evaluating different aspects of cognitive processing.

CHAPTER IV

DISCUSSION

The purpose of this study was to examine whether short-term auditory training or auditory-cognitive training produced significant changes in speech perception (i.e., syllable, word, or sentence identification in degraded or dichotic conditions), selected areas of cognitive processing (i.e., divided attention, working memory, and processing speed), and/or self-reported communication ability (i.e., ratings of function in average and adverse listening conditions, use of verbal and nonverbal strategies, discouragement and stress related to hearing difficulties, proportion of a passage understood, and communication confidence) in a group of older adults with mild-moderate sensorineural hearing loss. The short-term nature of the training was unique given that many training programs reported in the literature extend from 4-12 weeks (Burk & Humes, 2008; Miller, Watson, Kewley-Port, et al., 2008; Stacey & Summerfield, Stecker et al., 2006; Sweetow & Henderson Sabes, 2007. Shorter training programs are desirable because of compliance problems with completing the longer programs (Sweetow & Henderson-Sabes, 2010).

General Discussion

Research suggests that speech understanding, cognitive abilities and self-reported communication abilities are negatively impacted in older adults with and without hearing loss (Baddeley, 2000; 2003; Cox et al., 2008; CHABA, 1988; Gordon-Salant, 2005; Helfer & Freyman, 2008; Humes, 1996; Kricos & Holmes, 1996; McCoy et al., 2005; Pichora-Fuller, 2003; Stuart & Phillips, 1996; Wiley et al., 2000). In general, age-related anatomical degenerative changes in the peripheral and central regions of the brain are associated with decline in these abilities. These peripheral and central changes can impact auditory sensitivity, speech perceptual, and cognitive processing abilities (Divenyi, et al., 2005; Gordon-Salant, 2005; Pichora-Fuller & Souza, 2003; Tremblay et al., 2003).

One management approach for reducing speech perceptual and cognitive deficits is through the use of aural rehabilitation. Recently, home computer-based auditory training programs have become a promising tool for aural rehabilitation. Prior research does indicate that speech perceptual abilities in the elderly population may improve with auditory training (Miller, Watson, Kewley-Port, et al., 2008; Sweetow & Henderson Sabes, 2006, 2007; Sweetow & Palmer, 2005).

Although evidence does support the benefits of home-based auditory training, there is only one known study to date that has evaluated cognitive processing following training (Sweetow & Henderson Sabes, 2007). In addition to research on clinical auditory training programs, research-based auditory training protocols also have been reported as leading to improvements in syllable, word, and sentence identification (Burk et al., 2006; Stacey & Summerfield, 2008). However, further investigation is warranted to determine if short-term auditory training leads to improved speech perception.

The idea to investigate short-term auditory training versus long-term auditory training stemmed from information related to a beta version of the LACE program that only incorporated the degraded speech training components. A five day, short-term auditory-only training program was developed based on the degraded speech training components from within the LACE training program. The preliminary data reported indicated that those patients who had gone through the beta test pilot version of the short-term degraded speech training demonstrated benefit after six days of training that was comparable with the research evidence from those who completed the long-term (i.e., 4-weeks) LACE training program (verbal communication Dr. Dwayne Paschall, Texas Tech University, February 8, 2010).

The product from the beta test pilot version of the short-term degraded speech training program is not commercially available. Therefore, upon consideration and communication with the manufacturer of the LACE program, it was decided to use the LACE training program for the short-term training. Although the LACE training program is traditionally a 4-week training program, it does incorporate both the degraded speech and the cognitive training components that were of interest in the current investigation. The current research utilized the LACE training program in the following manner: one group of participants would complete six sessions of auditory-only and cognitive training while a second group would complete six sessions of auditory-only training.

One unique aspect of the current study was the use of a listening control group (i.e., short stories on CD). There is no published data to date regarding whether structured listening may serve as a control or alternatively might result in speech perceptual and/or cognitive changes in older adults. Because many older adults with hearing loss either wait several years before obtaining hearing aids or pursue no aural rehabilitation measures at all, it is of interest to determine if these adults might improve their speech perceptual and/or cognitive abilities through training. Thus, the purpose of the current study was to explore the impact of auditory and auditory-cognitive training on selected measures of speech perception, cognitive abilities, and self reported communication abilities and feelings.

For the current research, several questions were addressed relative to the impact of a one week listening training program on speech understanding, cognitive processing, and self-reported communication abilities. Thirty five participants between the ages of 60 and 80 were randomly placed into one of three listening training groups (LACE 4.0; LACE-Degraded or Librivox-short story control) and completed follow-up testing. Prior to the training, each participant underwent initial testing on six different speech perceptual tests (with 11 scored conditions), three cognitive processing tests (with four scored conditions), and three self-report test measures (with eight scored conditions). Statistical analyses revealed that there were no significant differences for age, hearing loss or baseline measures of speech perception, cognition or self-reported communication between the three training groups. That finding confirmed that the groups were similar prior to beginning their one-week training/control programs.

Impact of training protocol.

To answer the question as to whether speech perceptual, cognitive, and/or self-reported communication abilities improved following training or control activities MANOVA analyses were conducted on the data for each group.

The only group showing significant pre-post training differences on the speech perceptual measures was the LACE 4.0 training group. Significant differences were found on the Dichotic Sentence Identification (DSI) right ear and DSI left ear, Time Compressed Speech, and i-CAST time measures. The direction of change was for improvement on all of these measures. The question arises as to why only the auditory-cognitive training group (i.e., the LACE 4.0 group) showed significant changes in speech perception when the auditory-only training group (i.e., the LACE Degraded group) also received degraded speech training. Specifically, those in the LACE 4.0 group received approximately 126 minutes of degraded speech exercises and 54 minutes of cognitive exercises whereas those in the LACE-Degraded group received all 180 minutes in degraded speech exercises. Perhaps the cognitive exercises contributed to the improved speech perception in the LACE 4.0 group. This suggests the possibility that a cognitive training component contributes to improvement in speech perceptual abilities in older adults.

The only group showing significant pre-post differences on the cognitive measures was the LACE-Degraded training group. However, for that group, none of the specific tests reached the criteria of $p<0.05$. That finding suggests that the difference is not meaningful and therefore was not given further interpretation. The current results, while exploratory in nature, do not suggest significant change on these cognitive measures following the one-week training programs. Only the LACE 4.0 group received formal cognitive training. The approximately one hour of cognitive training in the LACE 4.0 group did not produce changes in attention, working memory or processing speed abilities in this group. In the original LACE 4.0 study (Sweetow & Henderson Sabes 2006; 2007) participants completed approximately 600 minutes of speech and cognitive training exercises and were found to have improvements in both speech perception and cognition. One difference between the current study and that of Sweetow and Henderson Sabes was the amount of cognitive training between the two studies (i.e., one hour in current study versus three hours in original LACE study). This may account for the lack of cognitive change in the current study. A second difference between the studies is their use of different assessments to evaluate processing speed and working memory. Their assessments (i.e., Listening Span Test-measure of processing speed; Stroop Color Word Test-measure of working memory) may be more sensitive to change.

The only group showing significant pre-post training differences on the self-report measures was the LACE 4.0 training group. One might expect improved self reports in this group as this is the only group that showed significant changes in speech perception. Specifically, significant differences were found on the CPHI Discouragement and CPHI Adverse

Scales. In the current study, for the Discouragement Scale, the change reflected improvement or less discouragement following training. For the Adverse scale, however, the change reflected a perception of lower effectiveness when communicating in difficult listening situations. That latter response was an unexpected result. The degraded speech exercises might sensitize individuals to their difficulties listening in adverse conditions. Based on that, however, one would expect to see perceptions of poorer performance in adverse situations in both the LACE 4.0 and LACE Degraded groups. It is a possibility that the additional cognitive exercises in the LACE 4.0 group contributed to an overall feeling of being less effective in adverse or challenging situations.

Overall, significant post-training changes were found only in the LACE 4.0 training group on selected measures of speech perception and self reported communication. These results are exploratory and are limited by the small sample size. It is promising that some changes were observed; however, further evaluation relative to the clinical implications for change following training is warranted.

Correlation Analyses: Relationships Between Cognitive and Self Report with Speech Perception Changes.

One question of interest to researchers is that of whether initial characteristics of listeners might be associated with changes in speech perception following auditory training. Research question two specifically addressed whether baseline cognitive measures (BTA, NR & ART) or baseline self-report measures (CPHI, SIR, CCP) were associated with change on any of the speech perceptual tests (WIN, CST, DSI, TC, DDT & i-CAST). Several moderate correlations were found between change scores on perceptual measures and baseline cognitive and self-report measures (CST & BTA, CST & ARTT Time, CST & ARTT Accuracy, i-CAST & SIR and WIN & CPHI-Verbal).

A significant positive correlation was found between the CST speech perceptual difference score and the BTA cognitive processing measure. The CST evaluates sentence identification in the presence of a multi-talker babble (Cox et al. 1988); while the BTA evaluates auditory divided attention (Schretlen, 2009). Both tests may be tapping into divided attention resources with the babble serving as the distracter on the CST task and the non-target words serving as the distracter on the BTA task. Those with higher initial scores on divided attention (BTA) were found to have greater improvement on a sentence in noise identification test (CST). Thus, suggesting the importance of attention in some speech perceptual tasks. Change on the CST was also negatively correlated with ARTT time and ARTT accuracy. Thus, greater performance change on the CST was associated with shorter initial ARTT times and poorer initial ARTT accuracy.

A moderate positive relationship was found between the i-CAST syllable identification difference scores and the initial SIR scores. The i-CAST syllable identification and SIR tests both use speech based material in noise. The i-CAST task specifically involves the identification of syllables (e.g., aBa, aDA, aGa, etc.) in the presence of speech-shaped noise (Fu & Galvin, 2005; 2007), while the SIR task involves a judgment as of the proportion of words heard within a passage in the presence of competing speakers (Cox & McDaniel, 1989). Those who perceived that they heard a greater proportion of words on initial testing showed greater improvement on the i-CAST syllable identification task. Based on these findings, the older participants in the current study demonstrated that their actual syllable identification abilities were associated with their perceived identification abilities.

A moderate negative relationship was found between the WIN difference scores and the CPHI Verbal Scale. Essentially, those reporting fewer verbal communication strategies prior to training, tended to show greater improvement on word in noise identification. The infrequent use of verbal communication strategies would be associated with poorer communication effectiveness or greater hearing handicap. Henderson Sabes and Sweetow (2007) found that those with greater hearing handicap (as measured by the HHIE) also tended to show greater improvements in speech perception (as measured by using the QuickSIN).

The current study is the first study to examine the relationship between change on a large variety of speech perceptual measures with initial selected cognitive processing and self-report measures. The results from the current study indicate that the BTA, ARTT and SIR show moderate correlations with performance change on selected speech perceptual test measures. The only other study to explore the relationship between baseline measures and speech perceptual outcomes (Henderson Sabes & Sweetow, 2007) also found small to moderate positive correlations between speech improvement scores and self-report scores (Kaplan et al.1997 and r=.48 for the Hearing Handicap Index for the Elderly; Ventry and Weinstein, 1982)].

Relationships Among Self Report Measures

This question addressed whether the self-report measures (CPHI, SIR and CCP) are examining the same or different self-reported communication aspects. The CPHI scales evaluated communication performance in average listening situations, communication performance in adverse listening situations, verbal communication strategies use, non-verbal communication strategies use, discouragement and stress. The SIR examines listener judgments as to the proportion of speech understand in a passage. Finally, the CCP evaluates self-reported confidence of communicating in different communication environments.

A few significant moderate positive correlations were found between some CPHI scales (Average and Adverse) and the CCP. The correlations between CPHI-Average and the CCP and the CPHI-Adverse and the CCP are of interest. Better self-reported listening performance in average and adverse listening situations tended to be associated with greater self-reported confidence. Individuals who believe that they are hearing more in various listening situations would be expected to have greater confidence. Similarly, the relationship between the CCP and the HHIE (another self-report) was explored by Sweetow and Henderson Sabes (2010) and a moderate positive correlation also was found.

Relationships Among Speech Perception Measures

The fourth question examined whether any of the initial speech perceptual measures (WIN, CST, DSI, TC, DDT & i-CAST).were significantly correlated. Many significant relationships were found in the correlations of speech perceptual measures. Moderate correlations among speech measures were expected because these tests share common elements such as some type of background noise. In this study there were two main categories of speech perceptual measures based on ASHA (2005): 1) degraded measures (WIN, CST, TC, and i-CAST) and 2) dichotic measures (DSI and DDT). It was expected that there would be significant correlations among measures within these categories. In the group of degraded speech measures, there are five main features: 1) form of degraded signal (i.e., noise, compression, or multi-talker babble); 2) type of speech signal (i.e, syllable, word, and sentence); 3) response format (i.e., open, topic-limited, closed); 4) presentation (i.e., monaural or binaural) and 5) speed component (i.e., fixed pace versus speed response). Based on a review of common features, it was found that the WIN and TC shared three out of five common features (i.e., words, open-response format and monaural presentation). The WIN and CST tests also had three out of five common features (i.e., multi-talker babble, monaural presentation, fixed presentation speed); while all other sets of test had fewer common features (i.e., 0-1 common features). That would lead one to predict significant correlations between the WIN and TC tests and between the WIN and CST tests. The WIN and TC tests were found to be highly correlated as predicted based on the extent of their shared common features. In fact, not only do both tests include words, open-format, and better ear presentation they also specifically use words from the NU-6 list. There is no known data that has examined the relationship between these measures. In situations where measures are highly correlated, one might argue for removing one of the measures from a test battery because they are offering similar information. The WIN and CST test were not significantly correlated even though they also shared three common features. One consideration is that of the presentation level of the babble compared with the presentation level of the target stimuli. In the WIN test, the babble was at a fixed level while the target speakers' voice was presented at various signal to babble levels. Conversely, for the CST test, presentation of the babble was at a fixed level and presentation level of the target speakers' voice also was at a fixed level. Humes (2007) points out that high frequency hearing loss does impact speech-recognition scores and as a result one may need an increased signal to noise ratio level for speech recognition abilities to improve. Therefore, it is possible that high frequency hearing loss for the participants in the current study overshadowed the shared common features between these tests. .

The dichotic tests differed in three ways: 1) signal, 2) presentation format and 3) speed component. The DSI and DDT shared two common features in that both were closed-set response tasks with a fixed presentation speed. Thus these tests would be expected to show some significant correlation. It was expected that ear scores within a test (e.g., DSI right ear and DSI left ear) would be significantly correlated; however, the correlation of greater interest was that between the two tests. Only one small significant correlation occurred between the DDT FR LT ear and the DSI LT ear tests.

There is no known data that has examined the relationship between these measures. In situations where measures are highly correlated, one might argue for removing one of the measures from a test battery because they are offering similar information.

Relationships Among Processing Speed Measures

Some researchers (Gordon-Salant & Fitzgibbons, 2001; Schneider et al., 2005; Vaughn et al., 2008; Wingfield, 1996) have suggested that measures of time compressed speech; auditory reaction time, and time completion for a speech task might all reflect aspects of processing speed. A significant correlation was expected between the ARTT, TC and i-CAST tests because they are all thought to evaluate the construct of processing speed. However, no significant correlation was found between these tests. When examining the features of each of these tests, it was observed that the ARTT and TC only share one common feature (i.e., words) but differ in format (closed versus open), response mode (motor versus verbal) and ear presentation (monaural versus binaural) and the TC and i-CAST tests share no common features (i.e., different response mode, signal, format and ear presentation). That may explain the lack of significant correlations between those measures. Vaughan et al (2008) had found a small negative correlation between measures of auditory reaction time and time-compressed speech. In the current study, the ARTT and i-CAST tests share three common features (i.e., response mode, closed format and ear presentation) thus it was surprising that no significant correlation was found between those measures. These observations may be due to overall scoring of these tasks and the time allotted for each tests. For the ARTT, time task scoring was based on the average time for responding to 30 stimuli. In addition, each participant had to respond within

500 ms before the next presentation of stimuli occurred, not providing time to pause between the presentation of the stimuli. In contrast, scoring on the i-CAST test was based on overall response time for selecting the 200 tokens with the participant being able to pause between presentations of stimuli. That is, the computer did not generate another presentation of the stimuli until the participant had chosen a token. This may have resulted in time scores that were too diverse for findings of remarkable correlations.

Of interest was the moderate correlation between the i-CAST time and i-CAST syllable identification measures. On the i-CAST, those individuals who completed the test more quickly tended to have better scores. On the i-CAST syllable identification task individuals are able to pause if uncertain as to what syllable they heard. Thus one would expect individuals those experiencing difficulty with syllable identification to take more time to complete the entire 200 syllable test.

Relationships Among Working Memory Measures

Three tests were used to examine cognitive processing. The BTA and NR tests traditionally have been described as cognitive processing measures of auditory divided attention and auditory working memory, respectively. Other researchers (Cameron & Dillon, 2005; Strouse & Wilson 1999; Strouse, Wilson, & Brush, 2000a) have suggested that the DDT test conditions may address auditory divided attention (DDT Free Recall) and working memory (DDT Directed Recall). In the current study, two of the tests addressed divided attention (BTA and DDT Free-Recall) and the other two addressed working memory (DDT Directed-Recall and NR). Thus, one might expect significant correlations between the BTA and the DDT Free-Recall, and between the DDT Directed-Recall and the NR. Of lesser interest were correlations between ear and task conditions on the same test (i.e., those which were found between measures such as the DDT FR left ear and DDT DR left ear).

The strongest correlations found were between the DDT FR and DDT DR tests. Theoretically, those two tests evaluate different cognitive processes (i.e., divided attention and working memory). Therefore the task features for these tests were examined. Task features included: 1) ear presentation (binaural or dichotic), 2) cueing (i.e., pre versus post), 3) response (i.e., count versus recall) and 4) stimulus manipulation (reversal or no reversal). When comparing the shared features between all of these cognitive tests, the DDT FR and DDT DR were found to have the greatest number of common features (i.e., dichotic, recall and no reversal required on response). Thus, tests that had more common task features were more highly correlated. Even though tasks can appear to tap similar cognitive processes, they still may differ with respect to task features that may be related to cognitive load.

Limitations of the Study

There are several overall limitations of this study. The small sample size is the primary limitation. Despite extensive recruitment efforts, recruitment was surprisingly difficult. It was challenging to recruit non-hearing aid users to participate even though these individuals knew they had some hearing loss. One possible explanation for this is that those with a known mild to moderate hearing loss not only are unlikely to pursue amplification, but also are unlikely to pursue any form of intervention including auditory training. A second potential reason individuals may not have participated may be due to misperceptions about the nature of the recruitment. Several participants expressed concern about responding and/or participating for even baseline audiometric evaluation due to being exposed to real-world advertisements that offer “free” diagnostic evaluations, only to then be pressured into purchasing a set of hearing aids. A third likely reason for the difficulty in recruitment may be due to distance and travel issues related to the need for traveling to the university research lab on two separate occasions. Many possible participants indicated that although they would have liked to participate, travelling to and from the facility would be problematic for them. Recruitment also may have been negatively impacted due to limited participant compensation. Although participants were provided with a free training DVD and $20.00 compensation for participating, the time and travel involved for completing the study may have outweighed the level of compensation received.

Another reason for low study enrollment may be associated with the relatively tight audiological inclusionary criteria in this study. Symmetrical mild-moderate sensorineural hearing loss without retrocochlear indicators is considered to be the most common hearing loss in older adults. However, using that criterion resulted in exclusion of 49 of 85 potential participants. Other researchers (Burk et al., 2006; Humes et al., 2006; Miller et al., 2008; Sweetow & Henderson Sabes, 2006; 2007) have used study samples with broader audiological criteria, and have found improvement following auditory training.

A few additional limitations of the current study include: 1) no information on participant educational level, 2) a possible post-training placebo effect, and 3) a possible post-testing bias due to lack of examiner blinding. The exclusion of data collection related to the participants' educational level may have a remarkable impact on training outcomes. This information may be beneficial in determining whether education level has an impact on improvement in testing post-training.

As training was short-term and post-testing was conducted immediately following training (i.e., within 7-10 days), post-testing results may reflect a placebo effect. That is, because the individual had just completed the training, the recent training exposure may have resulted in a overly heightened sensitivity to training effects. One way to address this potential problem may be to extend the time period between completion of training and post-testing data collection.

Lastly, the primary investigator was not blind to group assignment for administration of the post-testing battery used in this study. This may have introduced the possibility for some bias to during the administration of the post-test battery. The inclusion of a secondary tester for the administration of post testing may prevent this potential problem possibly impacting the results.

Implications for Future Research

The results from this study indicated that older adults were able to successfully complete home-based auditory training for 30 minutes a day for six days. Most auditory training programs, however, are longer than one week and compliance can be an issue with longer training regimens. Specifically, compliance for 3,000 individuals completing an auditory training program lasting one month or longer was as low as 30% (Sweetow & Henderson Sabes, 2010). Findings in the current study support changes following only one week of LACE 4.0 training. Further investigation of benefits from shorter term training programs is warranted.

In addition, further examination of the current test battery with a larger sample might confirm the types and extent of changes with the auditory training programs. Measures such as the DSI, TC, i-CAST Time and CPHI Scales which did show possible changes in this study should be further explored. Furthermore, examination of the impact of auditory-cognitive training, auditory-only training, and cognitive-only training with a larger sample size may reveal additional or different benefits related to short-term auditory training. Ideally, it would be optimal to use a clinic-based population, as these individuals are actively seeking out intervention and/or deficit specific management treatment options. The incorporation of electrophysiological measurements in the test battery may provide information relative to plasticity changes following the three different training regimens. This would provide further empirical evidence for the incorporation of training-based protocols in clinical management/treatment of individuals with hearing loss.

It also would be of interest to evaluate whether cochlear implant recipients would demonstrate benefit from the LACE 4.0 training program. Along this line of research, perhaps investigating the impact of auditory-cognitive training, auditory-only training, and cognitive-only training with cochlear implant recipients could potentially reveal additional evidence related to the extent of processing difficulties that this particular population may be experiencing. These different types of training may further enhance the benefits of cochlear implantation by helping the recipient transition from hearing acoustically to hearing optimally with the implant and lead to development of specific aural rehabilitation approaches for use with this population.

It was surprising that the current audiological criteria resulted in exclusion of 58% of willing participants. Therefore, broader audiological criteria may be necessary.

Although there were several initial cognitive and self report measures that were associated with change on speech perceptual measures, no single measure or measures were highly correlated with change. As other researchers have found, the best indicator of possible change lies not in the cognitive or self report measures but in the initial speech perceptual abilities, with poorer performers showing greater improvement over time (Kricos & Holmes, 1996; Lakshminarayanan & Tallal, 2007; Henderson Sabes & Sweetow, 2007). Thus, cognitive and self-report measures may not be ideal for predicting who might benefit from auditory or auditory-cognitive training, but may reflect changes following training. However, further investigation of self-reported communication abilities following training with longer time periods between training completion and outcome testing may reveal the true effect of training on self-reported communication abilities. Furthermore, periodic re-evaluation of self-reported communication abilities six-months to one-year following training also may provide insight as to specific effects of training with this measurement.

Summary and Conclusions

The purpose of this treatment study was to explore whether short-term auditory training or auditory-cognitive training produces changes in speech perceptual, cognitive, or self-reported communication abilities in older adults. These abilities were examined using digit, syllable, word and sentence identification tasks; processing speed measures; and paper and pencil self-reports. The paper and pencil self-reports and an auditory reaction time measure were administered in quiet whereas other tests included either the use of degraded speech (i.e., noise or multi-talker babble, time-compression) or a dichotic presentation.

The study was exploratory in nature because of the small sample size. However, there were improvements in speech perception and self-reported communication in the LACE 4.0 training group. A few moderate significant correlations were found between self-reports of communication performance and communication confidence, suggesting that performance and feelings are related to confidence. On performance tasks of speech perception and cognition, significant correlations were usually observed when tests shared common task features rather than sharing the same assessment domain/construct. Many significant correlations between speech perceptual measures were moderate and again reflected common task features between measures. The most interesting correlation was the strong correlation between the Words in

Noise test, a test assessing word identification in noise, and the Time Compressed Speech test. Both of these are tests of degraded speech that also have many common task features. In addition, the WIN and TC tests both use the NU 6 words as the stimuli material. Perhaps the combination of common features and use of the NU 6 word list contributed to the significant relationship. Only small to moderate correlations were found between processing speed measures (TC, ARTT and i-CAST time) which had different task features. Although processing speed tasks were all considered to be evaluating the same construct, small to moderate relationships suggest that these measures may be evaluating different aspects of processing speed. Small to moderate significant correlations were found between measures of cognitive processing (DDT, BTA and NR) with the strongest correlation between two tasks measuring different aspects of cognition (divided attention and working memory).

Thus, upon examination of the study correlations, findings indicated that those tests with the most common features tended to have the strongest relationships. Consideration of task features when using different tests to evaluate the same construct, may prove to be a useful mechanism for choosing which test to use in a given test battery. No initial cognitive processing or self-report measure was found to be highly correlated with improvement in speech perception.

The findings from the current study indicate improvements following the one-week LACE 4.0 training, a program with speech perceptual and cognitive tasks. Additional investigation with a larger sample is warranted to further explore the use of this aural rehabilitation program with older adults. No change was found for either the LACE-Degraded training or Librivox control over a one-week period of time. Unlike others studies, the current study focused on auditory and auditory-cognitive training in non-hearing aid users. These types of trainings may be a valid option for non-hearing aid users. Further confirmation of short-term training benefit is important because there is low compliance for completing the traditional longer training programs.

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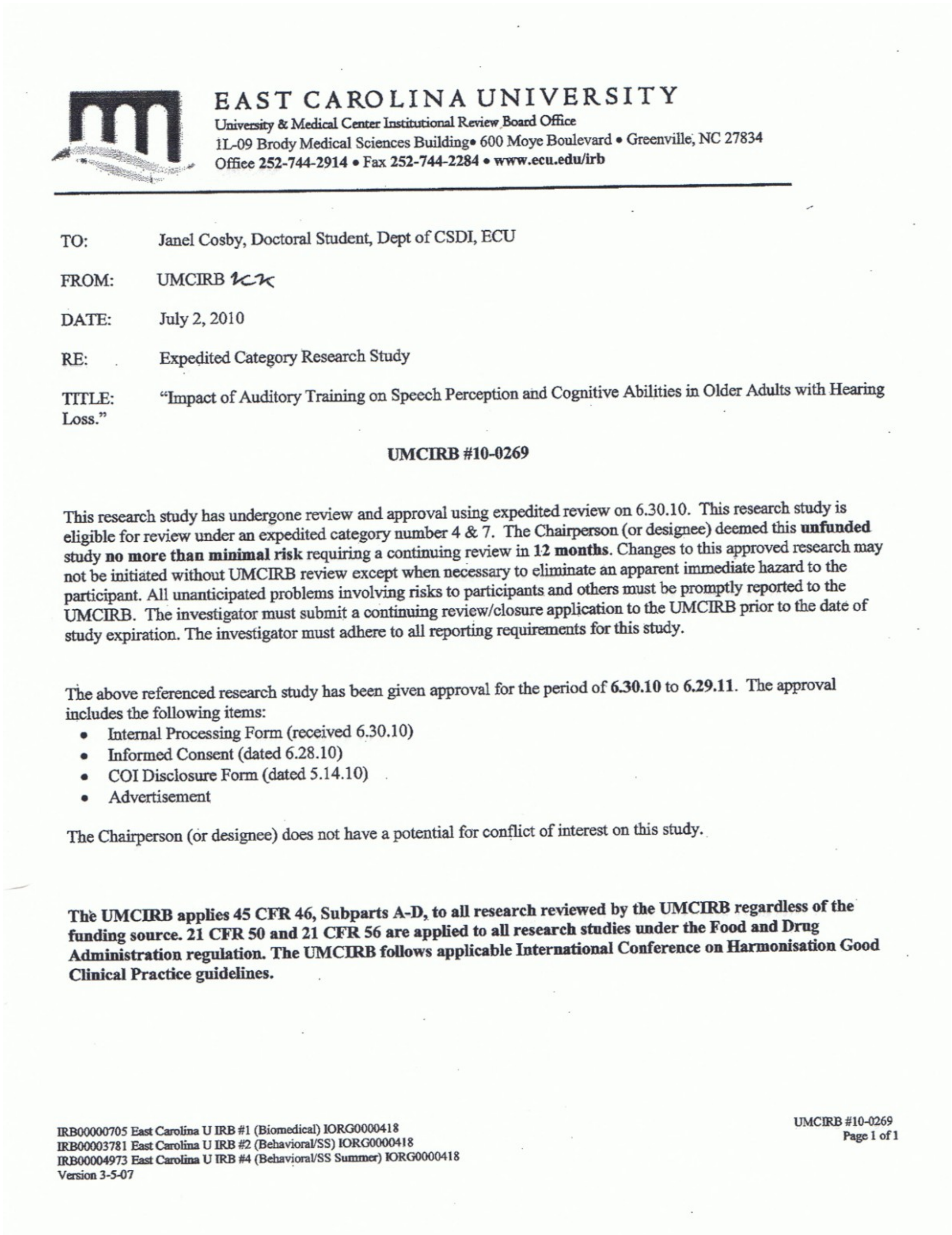
APPENDIX A: UMCIRB INSTITUTIONAL REVIEW BOARD APPROVAL LETTER, REVISION APPROVALS AND CONSENT DOCUMENT



EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
1L-09 Brody Medical Sciences Building• 600 Moye Boulevard • Greenville, NC 27834
Office 252-744-2914 • Fax 252-744-2284 • www.ecu.edu/irb

TO: Janel Cosby, Doctoral Student, Dept of CSDI, ECU

FROM: UMCIRB kk

DATE: July 2, 2010

RE: Expedited Category Research Study

TITLE: "Impact of Auditory Training on Speech Perception and Cognitive Abilities in Older Adults with Hearing Loss."

UMCIRB #10-0269

This research study has undergone review and approval using expedited review on 6.30.10. This research study is eligible for review under an expedited category number 4 & 7. The Chairperson (or designee) deemed this **unfunded** study **no more than minimal risk** requiring a continuing review in **12 months**. Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The investigator must adhere to all reporting requirements for this study.

The above referenced research study has been given approval for the period of **6.30.10** to **6.29.11**. The approval includes the following items:

- Internal Processing Form (received 6.30.10)
- Informed Consent (dated 6.28.10)
- COI Disclosure Form (dated 5.14.10)
- Advertisement

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

The UMCIRB applies 45 CFR 46, Subparts A-D, to all research reviewed by the UMCIRB regardless of the funding source. 21 CFR 50 and 21 CFR 56 are applied to all research studies under the Food and Drug Administration regulation. The UMCIRB follows applicable International Conference on Harmonisation Good Clinical Practice guidelines.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418
IRB00004973 East Carolina U IRB #4 (Behavioral/SS Summer) IORG0000418
Version 3-5-07

UMCIRB #10-0269
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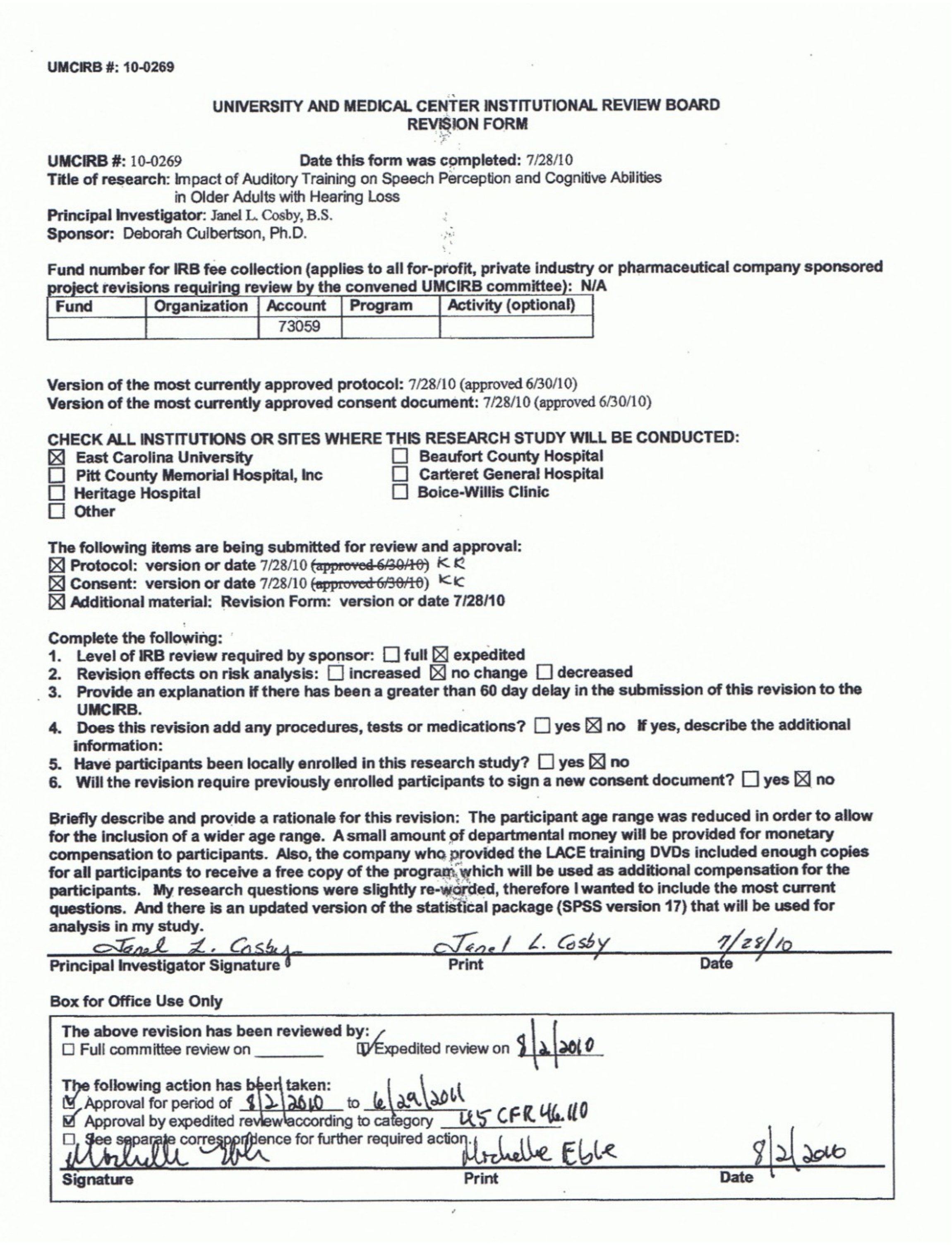


UMCIRB #: 10-0269

UNIVERSITY AND MEDICAL CENTER INSTITUTIONAL REVIEW BOARD
REVISION FORM

UMCIRB #: 10-0269 **Date this form was completed:** 7/28/10
Title of research: Impact of Auditory Training on Speech Perception and Cognitive Abilities in Older Adults with Hearing Loss
Principal Investigator: Janel L. Cosby, B.S.
Sponsor: Deborah Culbertson, Ph.D.

Fund number for IRB fee collection (applies to all for-profit, private industry or pharmaceutical company sponsored project revisions requiring review by the convened UMCIRB committee): N/A

Fund	Organization	Account	Program	Activity (optional)
		73059		

Version of the most currently approved protocol: 7/28/10 (approved 6/30/10)
Version of the most currently approved consent document: 7/28/10 (approved 6/30/10)

CHECK ALL INSTITUTIONS OR SITES WHERE THIS RESEARCH STUDY WILL BE CONDUCTED:

☒ **East Carolina University**
☐ **Pitt County Memorial Hospital, Inc**
☐ **Heritage Hospital**
☐ **Other**
☐ **Beaufort County Hospital**
☐ **Carteret General Hospital**
☐ **Boice-Willis Clinic**

The following items are being submitted for review and approval:

☒ **Protocol: version or date** 7/28/10 ~~(approved 6/30/10)~~ KK
☒ **Consent: version or date** 7/28/10 ~~(approved 6/30/10)~~ KK
☒ **Additional material: Revision Form: version or date 7/28/10**

Complete the following:

1. **Level of IRB review required by sponsor:** ☐ **full** ☒ **expedited**
2. **Revision effects on risk analysis:** ☐ **increased** ☒ **no change** ☐ **decreased**
3. **Provide an explanation if there has been a greater than 60 day delay in the submission of this revision to the UMCIRB.**
4. **Does this revision add any procedures, tests or medications?** ☐ **yes** ☒ **no If yes, describe the additional information:**
5. **Have participants been locally enrolled in this research study?** ☐ **yes** ☒ **no**
6. **Will the revision require previously enrolled participants to sign a new consent document?** ☐ **yes** ☒ **no**

Briefly describe and provide a rationale for this revision: The participant age range was reduced in order to allow for the inclusion of a wider age range. A small amount of departmental money will be provided for monetary compensation to participants. Also, the company who provided the LACE training DVDs included enough copies for all participants to receive a free copy of the program which will be used as additional compensation for the participants. My research questions were slightly re-worded, therefore I wanted to include the most current questions. And there is an updated version of the statistical package (SPSS version 17) that will be used for analysis in my study.

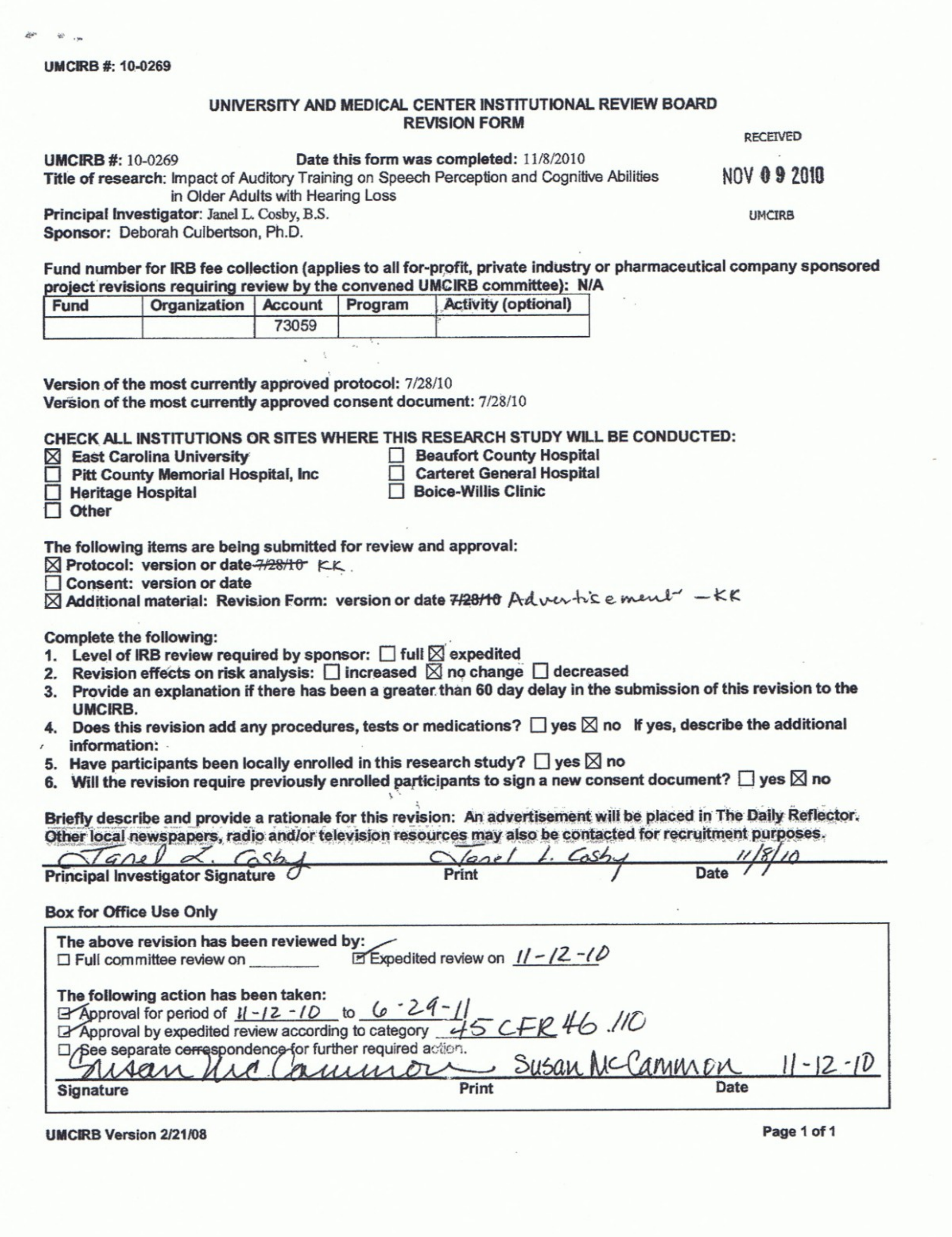
Janel L. Cosby Janel L. Cosby 7/28/10
Principal Investigator Signature **Print** **Date**

Box for Office Use Only

The above revision has been reviewed by:
☐ Full committee review on ________ ☑ Expedited review on 8/2/2010

The following action has been taken:
☑ Approval for period of 8/2/2010 to 6/29/2011
☑ Approval by expedited review according to category 45 CFR 46.110
☐ See separate correspondence for further required action.

Michelle Eble 8/2/2010
Signature **Print** **Date**



UMCIRB #: 10-0269

UNIVERSITY AND MEDICAL CENTER INSTITUTIONAL REVIEW BOARD
REVISION FORM

RECEIVED
NOV 09 2010
UMCIRB

UMCIRB #: 10-0269 **Date this form was completed:** 11/8/2010
Title of research: Impact of Auditory Training on Speech Perception and Cognitive Abilities in Older Adults with Hearing Loss
Principal Investigator: Janel L. Cosby, B.S.
Sponsor: Deborah Culbertson, Ph.D.

Fund number for IRB fee collection (applies to all for-profit, private industry or pharmaceutical company sponsored project revisions requiring review by the convened UMCIRB committee): N/A

Fund	Organization	Account	Program	Activity (optional)
		73059		

Version of the most currently approved protocol: 7/28/10
Version of the most currently approved consent document: 7/28/10

CHECK ALL INSTITUTIONS OR SITES WHERE THIS RESEARCH STUDY WILL BE CONDUCTED:

☒ **East Carolina University**
☐ **Pitt County Memorial Hospital, Inc**
☐ **Heritage Hospital**
☐ **Other**
☐ **Beaufort County Hospital**
☐ **Carteret General Hospital**
☐ **Boice-Willis Clinic**

The following items are being submitted for review and approval:
☒ **Protocol: version or date** ~~7/28/10~~ KK
☐ **Consent: version or date**
☒ **Additional material: Revision Form: version or date** ~~7/28/10~~ Advertisement —KK

Complete the following:

1. **Level of IRB review required by sponsor:** ☐ **full** ☒ **expedited**
2. **Revision effects on risk analysis:** ☐ **increased** ☒ **no change** ☐ **decreased**
3. **Provide an explanation if there has been a greater than 60 day delay in the submission of this revision to the UMCIRB.**
4. **Does this revision add any procedures, tests or medications?** ☐ **yes** ☒ **no If yes, describe the additional information:**
5. **Have participants been locally enrolled in this research study?** ☐ **yes** ☒ **no**
6. **Will the revision require previously enrolled participants to sign a new consent document?** ☐ **yes** ☒ **no**

Briefly describe and provide a rationale for this revision: An advertisement will be placed in The Daily Reflector. Other local newspapers, radio and/or television resources may also be contacted for recruitment purposes.

Janel L. Cosby Janel L. Cosby 11/8/10
Principal Investigator Signature **Print** **Date**

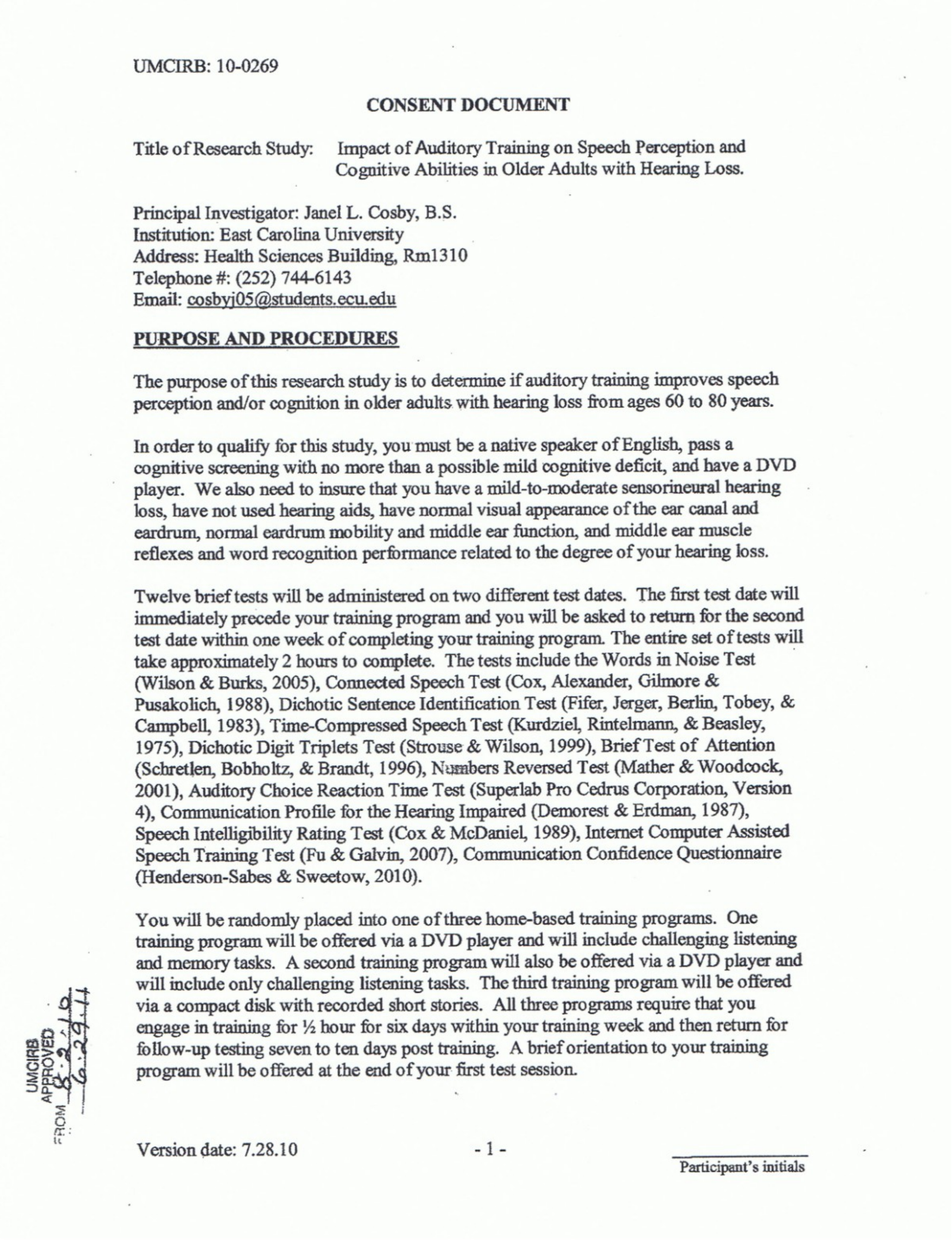
Box for Office Use Only

The above revision has been reviewed by:
☐ Full committee review on ________ ☑ Expedited review on 11-12-10

The following action has been taken:
☑ Approval for period of 11-12-10 to 6-29-11
☑ Approval by expedited review according to category 45 CFR 46.110
☐ See separate ~~correspondence~~ for further required action.

Susan McCammon Susan McCammon 11-12-10
Signature **Print** **Date**

UMCIRB Version 2/21/08 **Page 1 of 1**



UMCIRB: 10-0269

CONSENT DOCUMENT

Title of Research Study: Impact of Auditory Training on Speech Perception and Cognitive Abilities in Older Adults with Hearing Loss.

Principal Investigator: Janel L. Cosby, B.S.
Institution: East Carolina University
Address: Health Sciences Building, Rm1310
Telephone #: (252) 744-6143
Email: cosbyj05@students.ecu.edu

PURPOSE AND PROCEDURES

The purpose of this research study is to determine if auditory training improves speech perception and/or cognition in older adults with hearing loss from ages 60 to 80 years.

In order to qualify for this study, you must be a native speaker of English, pass a cognitive screening with no more than a possible mild cognitive deficit, and have a DVD player. We also need to insure that you have a mild-to-moderate sensorineural hearing loss, have not used hearing aids, have normal visual appearance of the ear canal and eardrum, normal eardrum mobility and middle ear function, and middle ear muscle reflexes and word recognition performance related to the degree of your hearing loss.

Twelve brief tests will be administered on two different test dates. The first test date will immediately precede your training program and you will be asked to return for the second test date within one week of completing your training program. The entire set of tests will take approximately 2 hours to complete. The tests include the Words in Noise Test (Wilson & Burks, 2005), Connected Speech Test (Cox, Alexander, Gilmore & Pusakolich, 1988), Dichotic Sentence Identification Test (Fifer, Jerger, Berlin, Tobey, & Campbell, 1983), Time-Compressed Speech Test (Kurdziel, Rintelmann, & Beasley, 1975), Dichotic Digit Triplets Test (Strouse & Wilson, 1999), Brief Test of Attention (Schretlen, Bobholtz, & Brandt, 1996), Numbers Reversed Test (Mather & Woodcock, 2001), Auditory Choice Reaction Time Test (Superlab Pro Cedrus Corporation, Version 4), Communication Profile for the Hearing Impaired (Demorest & Erdman, 1987), Speech Intelligibility Rating Test (Cox & McDaniel, 1989), Internet Computer Assisted Speech Training Test (Fu & Galvin, 2007), Communication Confidence Questionnaire (Henderson-Sabes & Sweetow, 2010).

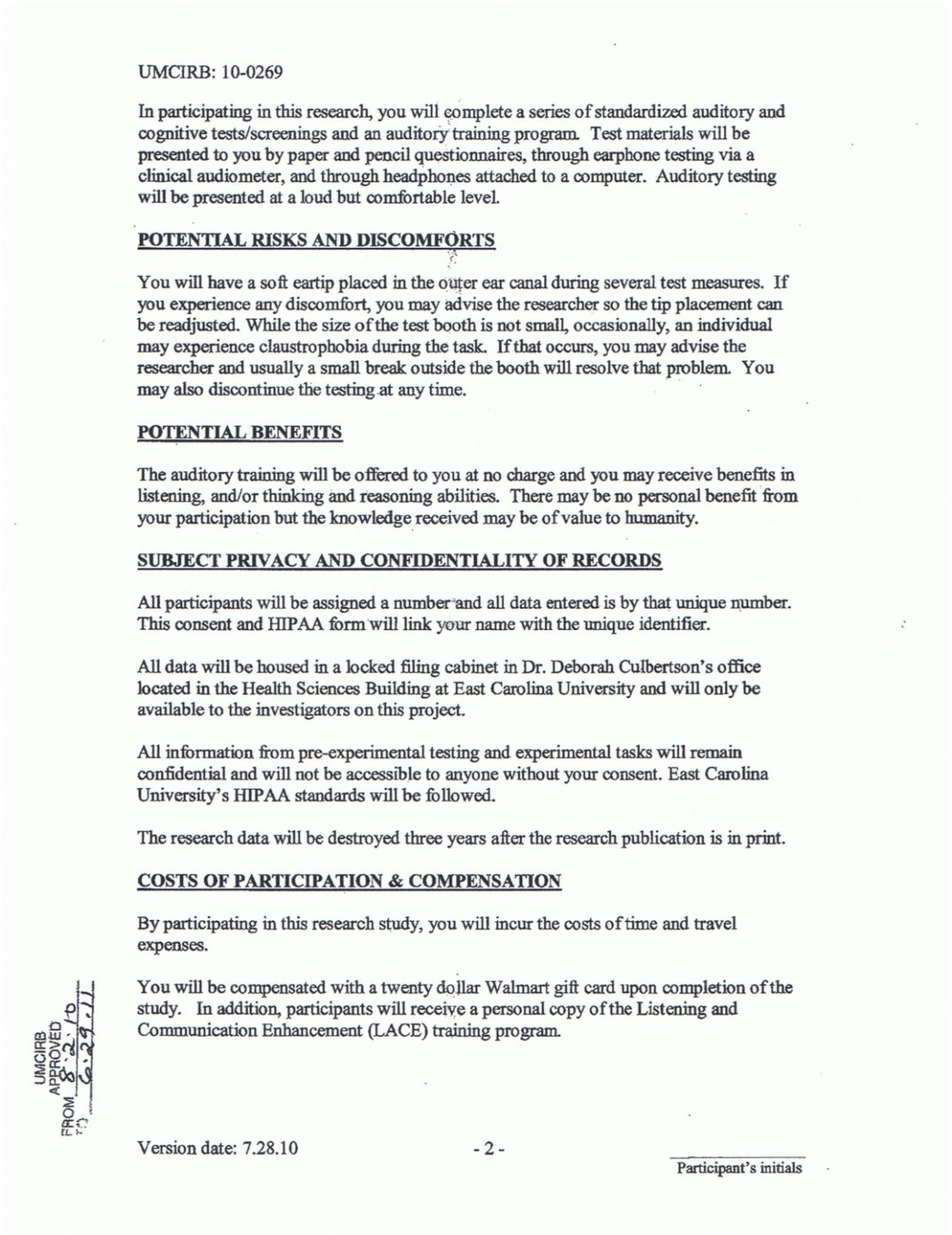
You will be randomly placed into one of three home-based training programs. One training program will be offered via a DVD player and will include challenging listening and memory tasks. A second training program will also be offered via a DVD player and will include only challenging listening tasks. The third training program will be offered via a compact disk with recorded short stories. All three programs require that you engage in training for ½ hour for six days within your training week and then return for follow-up testing seven to ten days post training. A brief orientation to your training program will be offered at the end of your first test session.

UMCIRB
APPROVED
FROM 8-2-10
6-29-11

Version date: 7.28.10

- 1 -

____
Participant's initials



UMCIRB: 10-0269

In participating in this research, you will complete a series of standardized auditory and cognitive tests/screenings and an auditory training program. Test materials will be presented to you by paper and pencil questionnaires, through earphone testing via a clinical audiometer, and through headphones attached to a computer. Auditory testing will be presented at a loud but comfortable level.

POTENTIAL RISKS AND DISCOMFORTS

You will have a soft eartip placed in the outer ear canal during several test measures. If you experience any discomfort, you may advise the researcher so the tip placement can be readjusted. While the size of the test booth is not small, occasionally, an individual may experience claustrophobia during the task. If that occurs, you may advise the researcher and usually a small break outside the booth will resolve that problem. You may also discontinue the testing at any time.

POTENTIAL BENEFITS

The auditory training will be offered to you at no charge and you may receive benefits in listening, and/or thinking and reasoning abilities. There may be no personal benefit from your participation but the knowledge received may be of value to humanity.

SUBJECT PRIVACY AND CONFIDENTIALITY OF RECORDS

All participants will be assigned a number and all data entered is by that unique number. This consent and HIPAA form will link your name with the unique identifier.

All data will be housed in a locked filing cabinet in Dr. Deborah Culbertson's office located in the Health Sciences Building at East Carolina University and will only be available to the investigators on this project.

All information from pre-experimental testing and experimental tasks will remain confidential and will not be accessible to anyone without your consent. East Carolina University's HIPAA standards will be followed.

The research data will be destroyed three years after the research publication is in print.

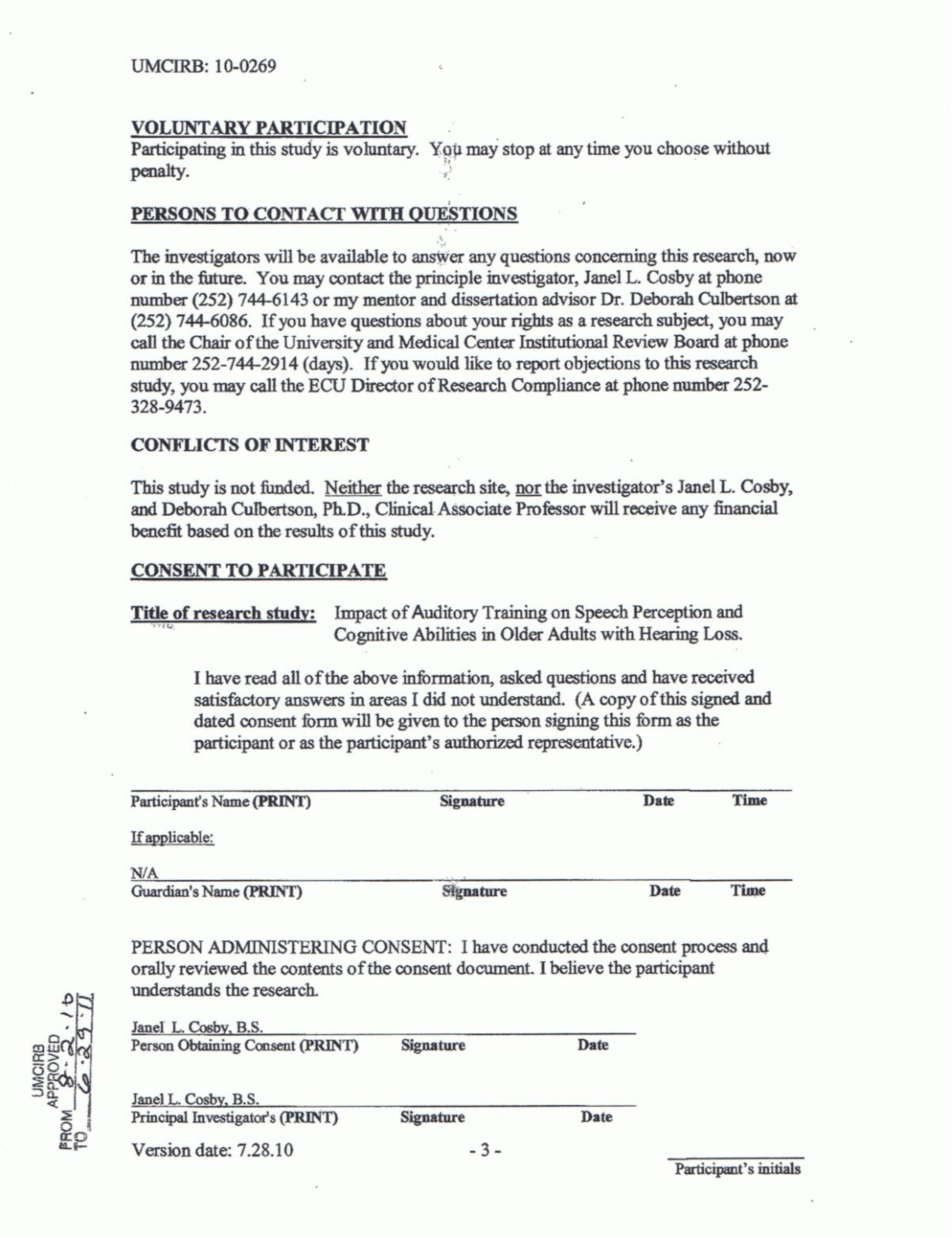
COSTS OF PARTICIPATION & COMPENSATION

By participating in this research study, you will incur the costs of time and travel expenses.

You will be compensated with a twenty dollar Walmart gift card upon completion of the study. In addition, participants will receive a personal copy of the Listening and Communication Enhancement (LACE) training program.

UMCIRB
APPROVED
FROM 8-2-10
TO 6-29-11

Participant's initials



UMCIRB: 10-0269

VOLUNTARY PARTICIPATION

Participating in this study is voluntary. You may stop at any time you choose without penalty.

PERSONS TO CONTACT WITH QUESTIONS

The investigators will be available to answer any questions concerning this research, now or in the future. You may contact the principle investigator, Janel L. Cosby at phone number (252) 744-6143 or my mentor and dissertation advisor Dr. Deborah Culbertson at (252) 744-6086. If you have questions about your rights as a research subject, you may call the Chair of the University and Medical Center Institutional Review Board at phone number 252-744-2914 (days). If you would like to report objections to this research study, you may call the ECU Director of Research Compliance at phone number 252-328-9473.

CONFLICTS OF INTEREST

This study is not funded. Neither the research site, nor the investigator's Janel L. Cosby, and Deborah Culbertson, Ph.D., Clinical Associate Professor will receive any financial benefit based on the results of this study.

CONSENT TO PARTICIPATE

Title of research study: Impact of Auditory Training on Speech Perception and Cognitive Abilities in Older Adults with Hearing Loss.

> I have read all of the above information, asked questions and have received satisfactory answers in areas I did not understand. (A copy of this signed and dated consent form will be given to the person signing this form as the participant or as the participant's authorized representative.)

Participant's Name **(PRINT)** **Signature** **Date** **Time**

If applicable:

N/A
Guardian's Name **(PRINT)** **Signature** **Date** **Time**

PERSON ADMINISTERING CONSENT: I have conducted the consent process and orally reviewed the contents of the consent document. I believe the participant understands the research.

Janel L. Cosby, B.S.
Person Obtaining Consent **(PRINT)** **Signature** **Date**

Janel L. Cosby, B.S.
Principal Investigator's **(PRINT)** **Signature** **Date**

UMCIRB
APPROVED
FROM 8-2-10
TO 6-29-11

Version date: 7.28.10 - 3 -

Participant's initials

APPENDIX B: RECRUITMENT FLYER

College of Allied Health Sciences | Department of Communication Sciences and Disorders
Health Sciences Building | Greenville, NC 27834

Hear Ye! Hear Ye!

Are you an adult between the ages of 60 and 80 who finds yourself struggling to understand speech clearly in certain situations?

If the answer is yes, then you may be eligible to participate in a listening training research study.

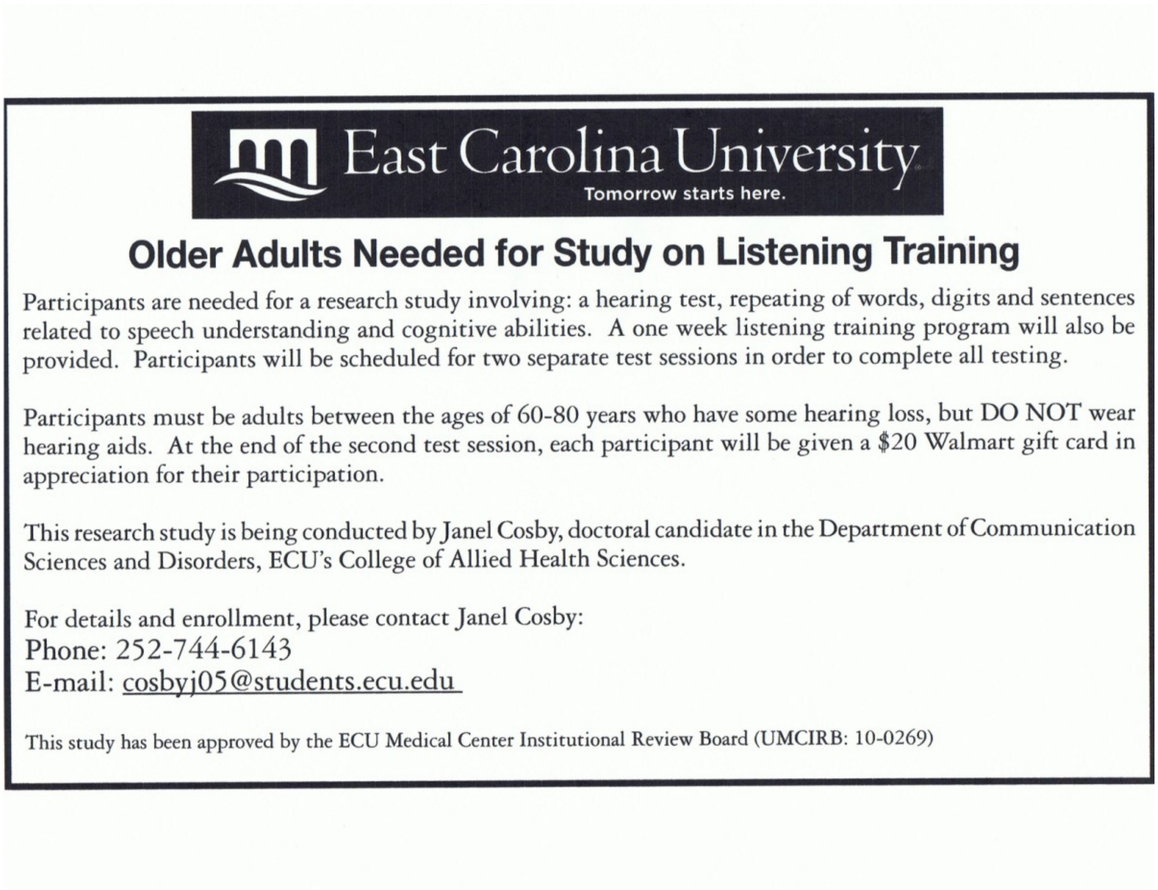
Sixty research participants are needed for audiological testing at East Carolina University and for an at home listening training program.

Individuals who do not currently use hearing aids are possibly eligible to participate in this listening training research study.

If interested in participation eligibility, please contact Janel Cosby by email at cosbyj05@students.ecu.edu or by phone at 252-744-6143.

East Carolina
UNIVERSITY

APPENDIX C: RECRUITMENT NEWSPAPER ADVERTISEMENT



East Carolina University
Tomorrow starts here.

Older Adults Needed for Study on Listening Training

Participants are needed for a research study involving: a hearing test, repeating of words, digits and sentences related to speech understanding and cognitive abilities. A one week listening training program will also be provided. Participants will be scheduled for two separate test sessions in order to complete all testing.

Participants must be adults between the ages of 60-80 years who have some hearing loss, but DO NOT wear hearing aids. At the end of the second test session, each participant will be given a $20 Walmart gift card in appreciation for their participation.

This research study is being conducted by Janel Cosby, doctoral candidate in the Department of Communication Sciences and Disorders, ECU's College of Allied Health Sciences.

For details and enrollment, please contact Janel Cosby:
Phone: 252-744-6143
E-mail: cosbyj05@students.ecu.edu

This study has been approved by the ECU Medical Center Institutional Review Board (UMCIRB: 10-0269)

APPENDIX D: CASE HISTORY FORM

East Carolina University
SPEECH-LANGUAGE AND HEARING CLINIC
Department of Communication Sciences and Disorders

Dissertation Case History Form

Part I: **General Information**

Name: ___________________________________ DOB: __________________

Address: _________________________________ Telephone: ____________ (H)
_________________________________ ____________ (C)
______ ____________________ (W)

Participant Id: ____________________________ Group #: _______________

Part II: **Exclusionary Criteria (Telephone Interview)**

Do you or a family member believe that you have hearing loss? Yes/No/Unsure

Have you worn or do you currently wear hearing aids? Yes/No

Have you had ear surgery in within the past 10 years? Yes/No

Part III: **Audiological (Face-to-Face)**

As an adult, have you ever had any ear infections? Yes/No

Do you perceive the hearing loss as being in one or both ears? One/Both

Do you have a family history of hearing loss? Yes/No

If yes, please list the relationship (i.e. parent, grandparent, sibling) or other family members with hearing.

In regards to the other family member(s) with hearing loss, is/was the hearing loss present throughout their lifespan? Yes/No

Have you or any members in your family with hearing loss ever had genetic testing?
Yes/No

Do you have a history of noise exposure? Yes/No

If yes, please describe (i.e. work related, recreation, military etc…).

Do you experience ringing in your ear(s)? Yes/No

If yes, does the ringing occur in one ear or both ears? One/Both

How often does the ringing occur and describe the ringing (i.e. high pitch, low pitch)?

Do you experience dizziness? Yes/No

If yes, please describe when the dizziness occurs and comment on how long the dizziness lasts.

Have you ever been evaluated for dizziness? Yes/No

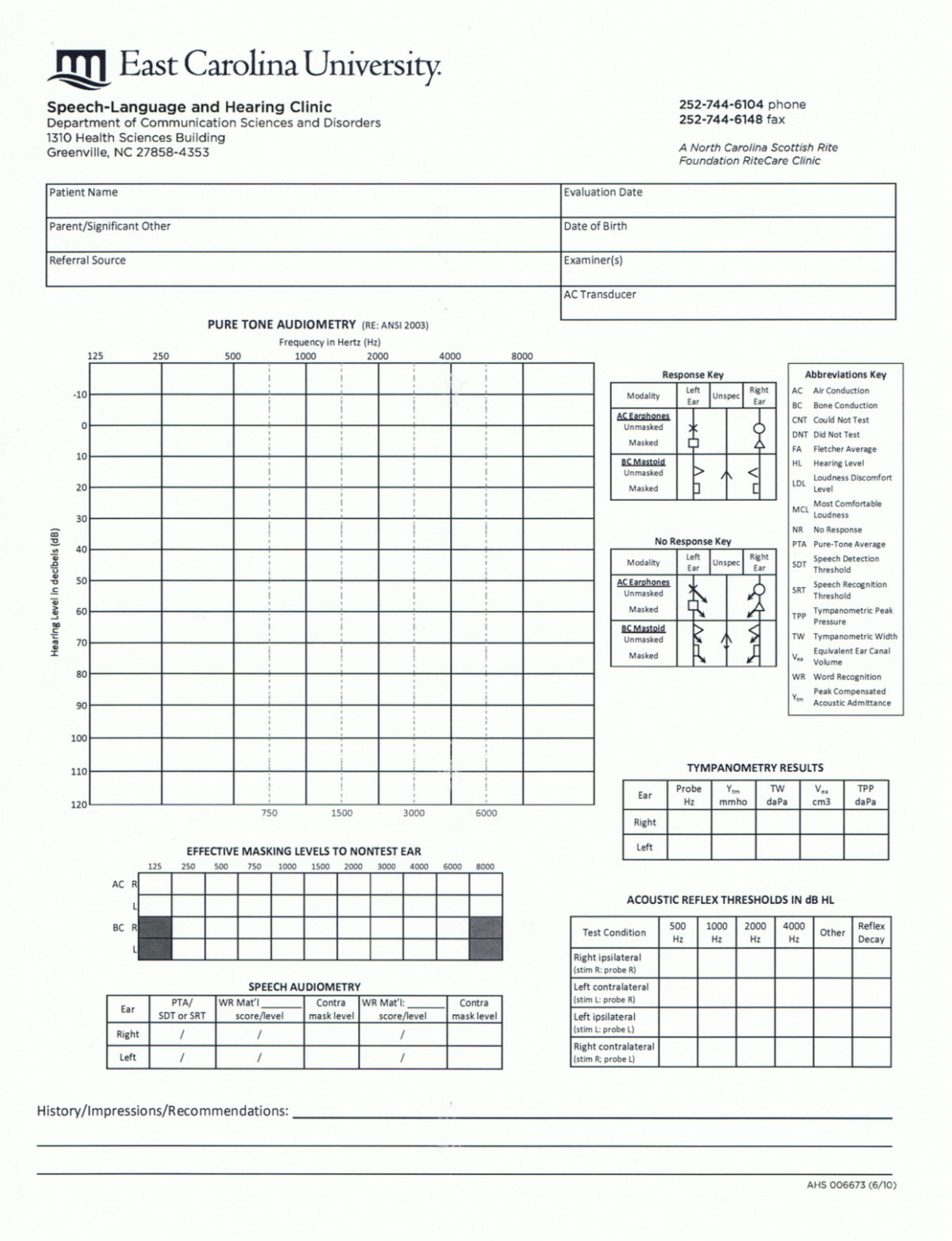
Do you experience aural fullness? Yes/No

Do you have access to a DVD player, stereo, or CPU w/ speakers? Yes/No

Do you have any other information you would like to share?

Do you have any questions you would like to ask?

APPENDIX E: AUDIOGRAM



East Carolina University.

Speech-Language and Hearing Clinic
Department of Communication Sciences and Disorders
1310 Health Sciences Building
Greenville, NC 27858-4353

252-744-6104 phone
252-744-6148 fax

A North Carolina Scottish Rite Foundation RiteCare Clinic

Patient Name	Evaluation Date
Parent/Significant Other	Date of Birth
Referral Source	Examiner(s)
	AC Transducer

PURE TONE AUDIOMETRY (RE: ANSI 2003)

Frequency in Hertz (Hz)

125 250 500 1000 2000 4000 8000

750 1500 3000 6000

Hearing Level in decibels (dB)

-10 0 10 20 30 40 50 60 70 80 90 100 110 120

Response Key

Modality	Left Ear	Unspec	Right Ear
AC Earphones Unmasked	×		○
Masked	□		△
BC Mastoid Unmasked	>	^	<
Masked	]		[

No Response Key

Modality	Left Ear	Unspec	Right Ear
AC Earphones Unmasked	×↘		↙○
Masked	□↘		↙△
BC Mastoid Unmasked	>↘	↑	↙<
Masked	]↘		↙[

Abbreviations Key

AC	Air Conduction
BC	Bone Conduction
CNT	Could Not Test
DNT	Did Not Test
FA	Fletcher Average
HL	Hearing Level
LDL	Loudness Discomfort Level
MCL	Most Comfortable Loudness
NR	No Response
PTA	Pure-Tone Average
SDT	Speech Detection Threshold
SRT	Speech Recognition Threshold
TPP	Tympanometric Peak Pressure
TW	Tympanometric Width
V_{ea}	Equivalent Ear Canal Volume
WR	Word Recognition
Y_{tm}	Peak Compensated Acoustic Admittance

TYMPANOMETRY RESULTS

Ear	Probe Hz	Y_{tm} mmho	TW daPa	V_{ea} cm3	TPP daPa
Right					
Left					

EFFECTIVE MASKING LEVELS TO NONTEST EAR

		125	250	500	750	1000	1500	2000	3000	4000	6000	8000
AC	R											
	L											
BC	R	▨										▨
	L	▨										▨

ACOUSTIC REFLEX THRESHOLDS IN dB HL

Test Condition	500 Hz	1000 Hz	2000 Hz	4000 Hz	Other	Reflex Decay
Right ipsilateral (stim R: probe R)						
Left contralateral (stim L: probe R)						
Left ipsilateral (stim L: probe L)						
Right contralateral (stim R; probe L)						

SPEECH AUDIOMETRY

Ear	PTA/ SDT or SRT	WR Mat'l ______ score/level	Contra mask level	WR Mat'l: ______ score/level	Contra mask level
Right	/	/		/	
Left	/	/		/	

History/Impressions/Recommendations: ______________________________

AHS 006673 (6/10)

APPENDIX F: MANOVA-AGE AND HEARING LOSS FOR ACROSS GROUPS

MANOVA: AGE AND HEARING LOSS ACROSS GROUPS

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.995	1810.361[a]	3.000	30.000	.000
	Wilks' Lambda	.005	1810.361[a]	3.000	30.000	.000
	Hotelling's Trace	181.036	1810.361[a]	3.000	30.000	.000
	Roy's Largest Root	181.036	1810.361[a]	3.000	30.000	.000
Group	Pillai's Trace	.050	.264	6.000	62.000	.952
	Wilks' Lambda	.951	.256[a]	6.000	60.000	.955
	Hotelling's Trace	.051	.248	6.000	58.000	.958
	Roy's Largest Root	.035	.366[b]	3.000	31.000	.778

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

c. Design: Intercept + Group

APPENDIX G: PRE-TRAINING GROUP MANOVA TABLE-SPEECH PERCEPTUAL MEASURES

PRE-TRAINING MANOVA: Speech Perceptual Measures

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.999	1438.024[a]	11.000	17.000	.000
	Wilks' Lambda	.001	1438.024[a]	11.000	17.000	.000
	Hotelling's Trace	930.486	1438.024[a]	11.000	17.000	.000
	Roy's Largest Root	930.486	1438.024[a]	11.000	17.000	.000
group	Pillai's Trace	.778	1.042	22.000	36.000	.445
	Wilks' Lambda	.323	1.173[a]	22.000	34.000	.331
	Hotelling's Trace	1.779	1.294	22.000	32.000	.248
	Roy's Largest Root	1.581	2.587[b]	11.000	18.000	.036

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

c. Design: Intercept + group

APPENDIX H: PRE-TRAINING GROUP MANOVA TABLE-COGNITIVE PROCESSING MEASURES

PRE-TRAINING MANOVA: Speech Perceptual Measures

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.982	380.820[a]	4.000	28.000	.000
	Wilks' Lambda	.018	380.820[a]	4.000	28.000	.000
	Hotelling's Trace	54.403	380.820[a]	4.000	28.000	.000
	Roy's Largest Root	54.403	380.820[a]	4.000	28.000	.000
group	Pillai's Trace	.226	.923	8.000	58.000	.505
	Wilks' Lambda	.783	.911[a]	8.000	56.000	.514
	Hotelling's Trace	.266	.898	8.000	54.000	.524
	Roy's Largest Root	.215	1.555[b]	4.000	29.000	.213

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

c. Design: Intercept + group

APPENDIX I: PRE-TRAINING GROUP MANOVA TABLE-SELF-REPORT MEASURES

PRE-TRAINING MANOVA: Self-Report Measures

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.990	271.772[a]	8.000	22.000	.000
	Wilks' Lambda	.010	271.772[a]	8.000	22.000	.000
	Hotelling's Trace	98.826	271.772[a]	8.000	22.000	.000
	Roy's Largest Root	98.826	271.772[a]	8.000	22.000	.000
group	Pillai's Trace	.563	1.126	16.000	46.000	.361
	Wilks' Lambda	.501	1.137[a]	16.000	44.000	.354
	Hotelling's Trace	.871	1.143	16.000	42.000	.351
	Roy's Largest Root	.686	1.971[b]	8.000	23.000	.097

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

c. Design: Intercept + group

APPENDIX J: MANOVA-SPEECH PERCEPTUAL MEASURES (LACE 4.0)

MANOVA Speech Perceptual Measures-LACE 4.0

Multivariate Tests[b,c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.999	89.145[a]	9.000	1.000	.082
	Wilks' Lambda	.001	89.145[a]	9.000	1.000	.082
	Hotelling's Trace	802.301	89.145[a]	9.000	1.000	.082
	Roy's Largest Root	802.301	89.145[a]	9.000	1.000	.082

a. Exact statistic;

b. Group = LACE 4.0;

c. Design: Intercept

APPENDIX K: MANOVA TESTS OF BETWEEN-SUBJECTS EFFECTS: SPEECH PERCEPTUAL MEASURES (LACE 4.0)

Tests of Between-Subjects Effects[b]

Source	**Dependent Variable**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**
Intercept	Pre-Post WIN Change	8.100	1	8.100	1.123	.317
	Pre-Post CST Change	57.600	1	57.600	.247	.631
	Pre-Post DSI RT Change	22.500	1	22.500	8.265	.018*
	Pre-Post DSI LT Change	62.500	1	62.500	6.657	.030*
	Pre-Post TC Change	108.900	1	108.900	5.695	.041*
	Pre-Post DDT FR RT Change	122.500	1	122.500	4.401	.065
	Pre-Post DDT FR LT Change	2.500	1	2.500	.066	.803
	Pre-Post DDT DR RT Change	1.600	1	1.600	.114	.743
	Pre-Post DDT DR LT Change	36.100	1	36.100	.590	.462
	Pre-Post i-CAST Time Change	4.900	1	4.900	7.230	.025*
	Pre-Post i-CAST Syllable Change	372.100	1	372.100	4.933	.053

b. Group = LACE 4.0;
Note: * $p < .05$; ** $p < .01$

APPENDIX L: MANOVA-SPEECH PERCEPTUAL MEASURES (LACE-DEGRADED

MANOVA Speech Perceptual Measures: LACE-Degraded

Multivariate Tests[b,c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.974	4.635[a]	8.000	1.000	.345
	Wilks' Lambda	.026	4.635[a]	8.000	1.000	.345
	Hotelling's Trace	37.080	4.635[a]	8.000	1.000	.345
	Roy's Largest Root	37.080	4.635[a]	8.000	1.000	.345

a. Exact statistic

b. group = Degraded

c. Design: Intercept

APPENDIX M: MANOVA-SPEECH PERCEPTUAL MEASURES (LIBRIVOX)

MANOVA Speech Perceptual Measures-Librivox

Multivariate Tests[b,c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.962	2.566[a]	10.000	1.000	.454
	Wilks' Lambda	.038	2.566[a]	10.000	1.000	.454
	Hotelling's Trace	25.656	2.566[a]	10.000	1.000	.454
	Roy's Largest Root	25.656	2.566[a]	10.000	1.000	.454

a. Exact statistic;
b. Group = Librivox;
c. Design: Intercept

APPENDIX N: MANOVA BETWEEN GROUPS CHANGE SCORE-SPEECH PERCEPTUAL MEASURES

MANOVA Change Scores Speech Perceptual Measures

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.864	9.796[a]	11.000	17.000	.000
	Wilks' Lambda	.136	9.796[a]	11.000	17.000	.000
	Hotelling's Trace	6.338	9.796[a]	11.000	17.000	.000
	Roy's Largest Root	6.338	9.796[a]	11.000	17.000	.000
group	Pillai's Trace	.998	1.629	22.000	36.000	.094
	Wilks' Lambda	.216	1.779[a]	22.000	34.000	.064
	Hotelling's Trace	2.639	1.919	22.000	32.000	.045
	Roy's Largest Root	2.186	3.577[b]	11.000	18.000	.008

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

c. Design: Intercept + group

APPENDIX O: MANOVA-COGNITIVE PROCESSING MEASURES (LACE 4.0)

MANOVA Cognitive Processing Measures (LACE 4.0)

Multivariate Tests[b,c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.210	.466[a]	4.000	7.000	.760
	Wilks' Lambda	.790	.466[a]	4.000	7.000	.760
	Hotelling's Trace	.266	.466[a]	4.000	7.000	.760
	Roy's Largest Root	.266	.466[a]	4.000	7.000	.760

a. Exact statistic

b. group = LACE 4.0

c. Design: Intercept

APPENDIX P: MANOVA-COGNITIVE PROCESSING MEASURES (LACE-DEGRADED)

MANOVA Cognitive Processing-Degraded

Multivariate Tests[b,c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.641	3.577[a]	4.000	8.000	.059
	Wilks' Lambda	.359	3.577[a]	4.000	8.000	.059
	Hotelling's Trace	1.788	3.577[a]	4.000	8.000	.059
	Roy's Largest Root	1.788	3.577[a]	4.000	8.000	.059

a. Exact statistic;
b. Group = Degraded;
c. Design: Intercept

APPENDIX Q: MANOVA TESTS OF BETWEEN-SUBJECTS EFFECTS (LACE-DEGRADED)

Tests of Between-Subjects Effects[b]

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Significance
Intercept	Pre-Post BTA Change	12.000	1	12.000	3.474	.089
	Pre-Post NR Change	1.333	1	.234	1.333	.638
	Pre-Post ARTT Time Change	31124.342	1	31124.342	.934	.355
	Pre-Post ARTT Task Change	33.333	1	33.333	.893	.365

b. Group = LACE-Degraded

APPENDIX R: MANOVA-COGNITIVE PROCESSING MEASURES (LIBRIVOX)

MANOVA Cognitive Processing Measures-Librivox

Multivariate Tests[b,c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.453	1.451[a]	4.000	7.000	.312
	Wilks' Lambda	.547	1.451[a]	4.000	7.000	.312
	Hotelling's Trace	.829	1.451[a]	4.000	7.000	.312
	Roy's Largest Root	.829	1.451[a]	4.000	7.000	.312

a. Exact statistic;
b. Group = Librivox;
c. Design: Intercept

APPENDIX S: MANOVA BETWEEN GROUPS CHANGE SCORE-COGNITIVE PROCESSING MEASURES

MANOVA Change Scores Speech Perceptual Measures

Multivariate Test Results

	Value	F	Hypothesis df	Error df	Sig.
Pillai's trace	.246	1.018	8.000	58.000	.433
Wilks' lambda	.763	1.016[a]	8.000	56.000	.435
Hotelling's trace	.299	1.011	8.000	54.000	.439
Roy's largest root	.253	1.835[b]	4.000	29.000	.149

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

APPENDIX T: MANOVA-SELF-REPORT COMMUNICATION MEASURES (LACE 4.0)

MANOVA-Self-Report Communication Measures (LACE 4.0)

Multivariate Tests[b,c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.932	5.157[a]	8.000	3.000	.102
	Wilks' Lambda	.068	5.157[a]	8.000	3.000	.102
	Hotelling's Trace	13.752	5.157[a]	8.000	3.000	.102
	Roy's Largest Root	13.752	5.157[a]	8.000	3.000	.102

a. Exact statistic

b. group = LACE 4.0

c. Design: Intercept

APPENDIX U MANOVA TESTS OF BETWEEN-SUBJECTS EFFECTS: (LACE 4.0)

Tests of Between-Subjects Effects[b]

Source	**Dependent Variable**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**
Intercept	Pre-Post CPHI Average Change	.004	1	.004	.015	.905
	Pre-Post CPHI Adverse Change	.663	1	.663	8.637	.015*
	Pre-Post CPHI Verbal Change	.058	1	.058	8.265	.584
	Pre-Post CPHI Non-Verbal Change	.058	1	.058	.181	.680
	Pre-Post CPHI Discouragement Change	2.183	1	2.183	15.510	.003**
	Pre-Post CPHI Stress Change	.263	1	.263	2.373	.154
	Pre-Post SIR Change	3.058	1	3.058	1.057	.328
	Pre-Post CCP Change	56.818	1	56.818	4.365	.063

b. Group = LACE 4.0;
Note: * p < .05; ** p < .01

APPENDIX V: MANOVA-SELF-REPORT COMMUNICATION MEASURES (LACE-DEGRADED)

MANOVA-Self-Report Communication Measures (LACE-Degraded)

Multivariate Tests[b,c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.919	4.257[a]	8.000	3.000	.130
	Wilks' Lambda	.081	4.257[a]	8.000	3.000	.130
	Hotelling's Trace	11.352	4.257[a]	8.000	3.000	.130
	Roy's Largest Root	11.352	4.257[a]	8.000	3.000	.130

a. Exact statistic

b. group = Degraded

c. Design: Intercept

APPENDIX W: MANOVA-SELF REPORT COMMUNICATION MEASURES (LIBRIVOX)

MANOVA-Self-Report Communication (Librivox)

Multivariate Tests[b,c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.516	.267[a]	8.000	2.000	.929
	Wilks' Lambda	.484	.267[a]	8.000	2.000	.929
	Hotelling's Trace	1.067	.267[a]	8.000	2.000	.929
	Roy's Largest Root	1.067	.267[a]	8.000	2.000	.929

a. Exact statistic;

b. Group = Librivox;

c. Design: Intercept

APPENDIX X: MANOVA BETWEEN GROUPS CHANGE SCORES-SELF REPORT MEASURES

MANOVA-Change Score Self-Report Measures

Multivariate Tests[c]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.288	1.113[a]	8.000	22.000	.392
	Wilks' Lambda	.712	1.113[a]	8.000	22.000	.392
	Hotelling's Trace	.405	1.113[a]	8.000	22.000	.392
	Roy's Largest Root	.405	1.113[a]	8.000	22.000	.392
group	Pillai's Trace	.680	1.482	16.000	46.000	.148
	Wilks' Lambda	.415	1.518[a]	16.000	44.000	.136
	Hotelling's Trace	1.180	1.548	16.000	42.000	.128
	Roy's Largest Root	.934	2.685[b]	8.000	23.000	.030

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

c. Design: Intercept + group