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## AUDITORY TRAINING AT HOME FOR ADULT HEARING AID USERS

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ABSTRACT OF DISSERTATION

Anne D. Olson

The Graduate School  
University of Kentucky  
2010

AUDITORY TRAINING AT HOME FOR ADULT HEARING AID USERS

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ABSTRACT OF DISSERTATION

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A dissertation submitted in partial fulfillment of the requirements  
for the degree of Doctor of Philosophy in Rehabilitation Sciences  
in the College of Health Sciences  
at the University of Kentucky

By

Anne D. Olson

Lexington, Kentucky

Co-Directors: Dr. Sharon Stewart, Associate Professor of Communication Sciences and  
Disorders

and Dr. Susan Effgen, Professor of Physical Therapy

Lexington, Kentucky

2010

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## ABSTRACT OF DISSERTATION

### AUDITORY TRAINING AT HOME FOR ADULT HEARING AID USERS

Research has shown that re-learning to understand speech in noise can be a difficult task for adults with hearing aids (HA). If HA users want to improve their speech understanding ability, specific training may be needed. Auditory training is one type of intervention that may enhance listening abilities for adult HA users.

The purpose of this study was to examine the behavioral effects of an auditory training program called Listening and Communication Enhancement (LACE™) in the Digital Video Display (DVD) format in new and experienced HA users. No research to date has been conducted on the efficacy of this training program.

An experimental, repeated measures group design was used. Twenty-six adults with hearing loss participated in this experiment and were assigned to one of three groups: New HA + training, Experienced HA + training or New HA – control. Participants in the training groups completed twenty, 30 minute training lessons from the LACE™ DVD program at home over a period of 4-weeks. Trained group participants were evaluated at baseline, after 2-weeks of training and again after 4- weeks of training. Participants in the control group were evaluated at baseline and after 4-weeks of HA use.

Findings indicate that both new and experienced users improved their understanding of speech in noise after training and perception of communication function. Effect size calculations suggested that a larger training effect was observed for new HA users compared to experienced HA users. New HA users also reported greater benefit from training compared to experienced users. Auditory training with the LACE™ DVD format should be encouraged, particularly among new HA users to improve understanding speech in noise.

KEYWORDS: Older Adult, Hearing Aids, Auditory Training, Cognition, Speech in Noise

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April 1, 2010  
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DISSERTATION

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AUDITORY TRAINING AT HOME FOR ADULT HEARING AID USERS

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## DEDICATION

This dissertation is dedicated to two groups of people; those who have inspired me and those who have sustained me.

First, to the many people with hearing loss with whom I have interacted throughout my professional life. The hurdles and barriers you confront in everyday conversations are often overlooked by society. Those challenges have been the motivation behind this research.

Second, to my family, who over the years have grounded me, yet allowed me to grow. I am forever grateful to my husband, Steve Olson for his steadfast support and to our children; Colin, Kirsten and Kathryn for your tolerance of me, and love for me while I worked through this process.

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Next, I wish to thank other members of my committee. Dr. Elizabeth Lorch, from the Department of Psychology, challenged my thinking and expanded my appreciation for the role of cognition in hearing. I am also very grateful to Dr. Malachy Bishop for serving as outside examiner.

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I am also truly appreciative to the entire faculty in the Department of Communication Sciences and Disorders who supported me throughout my program of study while I also served as a faculty member in this Department. It was my good fortune that I could learn from each of your unique strengths and abilities. Thank you for all of your individual contributions to the enrichment of my educational experience.

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Finally, I need to thank my family and friends. I am blessed to have a network of many good friends, both near and far, as well as two sisters who all contributed to keeping me going and keeping me sane. It is a privilege to thank my father, Ed Desmarais, along with the memory of my mother, Mary Desmarais, for always encouraging me to work hard. I thank my children, Colin, Kirsten, and Kathryn; I know it has not always been easy for you to have me away from home while working on this project. In spite of my frequent absence, you have grown up into very capable and independent individuals. I am very proud of each of you. As you begin to compose your own lives, I hope that each of you finds something that inspires you as I have. And lastly, my deepest appreciation is to my husband, Steve. Thank you for anchoring our home and family while I worked to complete the present project. While I am truly grateful for everything you did to keep us going, what I appreciate most, is your deep and abiding faith in me and my ability to complete this research.

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## Chapter One – Introduction

### Overview

Research has shown that re-learning to understand speech can be a difficult task for adults with hearing aids (HA) (Pichora-Fuller, Schneider, & Daneman, 1995). This is particularly true in adverse listening conditions such as noise or reverberation (Tun & Wingfield, 1999). Even after extended use, many HA users perceive minimal benefit from amplification (Kochkin, 2005). While overall outcomes show improved audibility in quiet environments, improved communication function and a reduction in perception of handicap (Chisolm et al., 2007), difficulty understanding speech in noise remains the most frequently cited complaint even among users with advanced digital technologies (Takahashi et al., 2007).

Another hallmark of outcomes research with adult HA users is the variability in amount of benefit observed. For example, some HA users seem to benefit from advanced technologies while others do not (van Tasell, Larsen, & Fabry, 1988; Gatehouse, 1994). Cox and Alexander (1991) found that HA benefit appeared to be related to speech understanding in quiet, but was not correlated with speech understanding in noise. Many researchers have proposed that there are individual differences in ability to understand speech in noise even when hearing loss is the same (Preminger & Wiley, 1985; Plomp, 1986; Crandell, 1991). In fact, Crandell (1991) reported that speech recognition thresholds in noise could vary between persons with identical hearing loss as much as 15 dB SPL. He interpreted these findings as evidence that there are individual differences in a person's susceptibility to noise even when controlled for hearing loss. Such individual differences may partially explain the variation clinically observed in terms of amount of benefit from amplification.

Recently, cognitive ability has also emerged as a variable that may affect outcome of auditory rehabilitative efforts (Kricos, 2006). Of particular relevance for HA users is the observation that listening to speech in noise is a complex task. As such, it requires listeners to attend to a primary target, yet ignore a competing signal. To do this takes extra cognitive effort such that persons with higher cognitive ability (i.e. attention, memory and processing) may have additional resources that can be allocated for such

tasks in comparison to persons with lower cognitive ability (Pichora-Fuller & Singh, 2006). So, while the use of amplification may improve audibility, it does not reduce the excessive cognitive demand required to process speech in noise, especially for older adults (Pichora-Fuller et al., 1995). Given that most HA users are older adults who find listening in noise challenging; the role of cognition will be explored in this study.

Different types of auditory rehabilitative (AR) efforts beyond amplification may provide adult HA users with additional benefit to facilitate listening in noise. Kricos (2006) called on audiologists to provide “comprehensive” audiologic rehabilitation services for our clients. One way to do this is to expand our thinking and incorporate alternative interventions similar to other professional disciplines such as physical therapy, occupational therapy and/or speech therapy. Auditory training is one type of rehabilitation that may enhance listening abilities for HA users and is the subject of this dissertation.

Current clinical practice patterns suggest that adults seeking amplification typically receive their device with detailed instruction about operation, but are provided with minimal opportunity for additional training (Prendergast & Kelly, 2002). Although clinicians are aware of the potential benefits of such programs (Hawkins, 2005), access to traditional therapy programs in clinic settings is limited for several reasons. First, most clinical settings have inadequate time during which to provide rehabilitation. In addition, such services are often not reimbursed and finally, there is not an overwhelming consensus that training really works (Sweetow & Palmer, 2005). Thus, the traditional dispensing model lacks any significant rehabilitation component that may facilitate listening in noise.

A newly developed training program called LACE™ (Listening and Communication Enhancement) (Sweetow & Sabes, 2006) is commercially available. A computerized version is available so that users can complete the training at home on their own computer. Audiologists can monitor the client’s progress remotely via a secure website. The computer version of LACE™ is a sentence-based program that features training lessons on speech in noise, rapid speech, competing speech, and auditory memory; additional features about this training program are shown in Table 1.1. Overall, Sweetow and Sabes (2006) reported behavioral improvements in ability to understand

speech in noise, as well as a small but significant reduction in perception of handicap after one month of training.

The LACE™ program is also available in a digital video display (DVD) format. The DVD version was created with the idea that it might be easier for older adults to operate compared to a computer. Several features of the DVD format are the same as the computerized version. For example, both provide sentence-based training that is self-paced and adaptive, so that training is neither too hard nor too difficult. There remain several differences between the two formats which are highlighted in Table 1.1. One key difference between the computerized and DVD version is that the duration of the training with the computer program is 4 weeks, whereas the duration of training with the DVD is only 2-weeks.

Table 1.1 Comparison of features in computer and DVD versions of the LACE™ training program.

	Computer Version of LACE™	DVD Version of LACE™
Number of lessons	20	10
Daily training time	30 minutes	30 minutes
Time to complete	4-weeks	2-weeks
Training Tasks	Speech in Noise Competing Speaker Rapid Speech Auditory Memory	Speech in Noise Competing Speaker Rapid Speech
Compliance	Monitored remotely over secure internet connection	Based on patient report
Additional Content	Communication Tips	Communication Tips
Cost	\$150.00 *	\$150.00 *
Evidence	Clinical trials conducted	No clinical trials conducted

\* Suggested retail price

In a study with the computerized training version, Sweetow and Sabes (2006) reported that most of the improvement for the experienced HA users occurred during the

first 2-weeks of training. Duration of training is a key concern for audiologists who will recommend such training for their patients. Given that the LACE™ DVD training program was designed to be completed in 2-weeks, it is important to determine if training for this length of time is adequate. One could hypothesize that performance could peak after 2-weeks of training and plateau, or performance could continue to improve with continued training. While the computer program has undergone examination with a target population of experienced HA users in a multi-site clinical trial (Sweetow & Sabes, 2006; Sweetow & Sabes, 2007), the DVD program has not.

Another issue that is not clear from the Sweetow and Sabes (2006) investigation is the effect of training on new HA users. “New” implies that an individual has recently obtained amplification. Currently there is no consensus on what constitutes someone as a new user since it has been defined in the literature as ranging anywhere from one day (Stecker et al., 2006) to six months (Munro & Lutman, 2004; Sweetow & Sabes, 2006). The extent of the effect of training on new HA users is not known because only experienced (> 6 months to 44 years) HA users were enrolled in the original clinical trial (Sweetow & Sabes (2006). One could hypothesize that new users may actually obtain greater benefit from such training due to plasticity. Therefore additional research is needed to determine if the DVD training format has any measureable impact on an individual’s ability to complete daily activities as well as reduce participation restrictions for new users as well as experienced users.

Aural rehabilitation is experiencing a resurgence of sorts for two converging reasons. First, neuroscience research has shown that direct remediation techniques such as auditory training alter central auditory nervous system responsiveness in animals (Recanzone, Schreiner, & Merzenich, 1993; Mercado, Bao, Orduna, Gluck, & Merzenich, 2001). Direct remediation approaches have been shown to be beneficial in children with language learning impairments (Tallal et al., 1996; Moore, Halliday, & Amitay, 2009), and in children with auditory processing disorders (Musiek, Shinn, & Hare, 2002). These studies illustrate the concept of auditory plasticity (Neuman, 2005) which can be defined as the extent to which the auditory system can be modified or changed specifically after training.

Second, as technology has improved, computerized training programs now allow patients to train in their home environment rather than receive training in a clinical setting. The development of such training programs have the potential to fundamentally change HA dispensing protocols by expanding the type of interventions available. Therefore, this research will empirically investigate the efficacy of the LACE™ DVD training program in both new and experienced HA users. Furthermore, it may provide additional insight about the role of cognition following training in this target population.

### *Purpose of Study*

The primary purpose of this study is to examine the behavioral effects of a home auditory training program in new and experienced HA users. As mentioned previously, the LACE™ training program (Sweetow & Sabes, 2006) is a commercially available training program that adult HA users can use at home. While observations from the Sweetow and Sabes study suggested that the computer training format was beneficial for experienced users, it was not clear if similar improvements may be observed with the DVD format. In addition, it is not clear if comparable benefits occur for both new and experienced HA users. Therefore several research questions will be examined in this study.

## Research Questions and Hypotheses

### *Question 1a*

Does the use of a home auditory training program in a DVD format for 4-weeks result in improved speech understanding in noise for new and experienced adult HA users alike who receive the training compared to a control group of new HA users who do not receive the training?

*Hypothesis 1a.* New HA users will obtain greater improvement in understanding speech in noise after 4-weeks of training compared to experienced HA users. In addition, new HA users who receive the training will obtain greater improvement in understanding speech in noise compared to new HA users in the control group who do not receive the training. The null hypothesis is that there will be no difference in listening abilities (as indicated by the speech in noise assessment) between the new (> 4-weeks, but <6 months) and experienced (>2 years) adult HA users who received the

training. Persons with HA use between 6 months and 2 years were not included in this study to clearly demarcate between new and experienced. Furthermore, there will be no difference in ability to understand speech in noise between new users in the treatment group and new users in the control group.

#### *Question 1b*

Does the use of a home auditory training program in a DVD format for 4-weeks result in improved understanding of rapid speech for new and experienced adult HA users alike who receive the training compared to a control group of new HA users who do not receive the training?

*Hypothesis 1b.* New HA users will obtain greater improvement in understanding rapid speech after 4-weeks of training compared to experienced HA users. In addition, new HA users who receive the training will obtain greater improvement in understanding rapid speech compared to new HA users in the control group who do not receive the training. The null hypothesis is that there will be no difference in listening abilities (as indicated by the rapid speech assessment) between the new (> 4-weeks, but <6 months) and experienced (>2 years) adult HA users who received the training. Furthermore, there will be no difference in ability to understand rapid speech between new users in the treatment group and new users in the control group.

#### *Question 1c*

Does the use of a home auditory training program in a DVD format for 4-weeks result in improved understanding of competing speech for new and experienced adult HA users alike who receive the training compared to a control group of new HA users who do not receive the training?

*Hypothesis 1c.* New HA users will obtain greater improvement in understanding competing speech after 4-weeks of training compared to experienced HA users. In addition, new HA users who receive the training will obtain greater improvement in understanding competing speech compared to new HA users in the control group who do not receive the training. The null hypothesis is that there will be no difference in listening abilities (as indicated by the competing speaker assessment) between the new (> 4-weeks, but <6 months) and experienced (>2 years) adult HA users who received the training.



Furthermore, there will be no difference in ability to understand competing speech between new users in the treatment group and new users in the control group.

### *Question 2*

Is there a difference in ability to understand speech in noise after 2-weeks of training compared to 4-weeks of training between groups?

*Hypothesis 2.* It was hypothesized that most of the improvement from DVD training program would occur in the first 2-weeks of training and that performance would essentially plateau for both new and experienced HA users in the trained groups after an additional 2-weeks of training. The current study tested the null hypothesis that there will be no statistical difference in understanding speech in noise after 2-weeks of training compared to 4-weeks of training for new and experienced HA users. Control subjects were not included in this analysis, because they were not tested at the 2-week interval.

### *Question 3*

Does the use of a home auditory training program lead to changes in perceived functional hearing abilities in daily life by adults who are new and experienced HA users compared to those who do not complete the training?

*Hypothesis 3.* Participants in both training groups may perceive small, but significant improvement in functional communication abilities based on self assessment after training. In addition, participants in the New HA + Training group will demonstrate additional improvement in functional communication compared to the New HA users in the control group. The null hypothesis is that the use of the LACE™ DVD auditory training program for 4-weeks will result in no significant difference in functional hearing abilities as measured by a self assessment questionnaire in new and experienced adult HA users who receive the training. Furthermore, there will be no difference in functional hearing abilities in the new HA users who receive the training and the new HA users in the control group who do not receive the training.

*Question 4*

Is there a difference in perception of benefit from treatment based on self assessment between new and experienced users?

*Hypothesis 4.* There may be differences in the perception of amount of benefit from training between groups of participants. Specifically, new users will perceive more benefit from training than experienced users. The null hypothesis tested was that there was no significant difference between the perception of benefit from training in new and experienced HA users after 4-weeks of training as measured by a self assessment questionnaire.

*Question 5*

Is there a relationship between working memory and the amount of benefit from training? Specifically, does working memory contribute to predicting outcome from training?

*Hypothesis 5.* Working memory will contribute significantly to explaining the amount of benefit obtained by participants in the training groups. This study will test the null hypothesis that there will be no difference in the percentage of variance explained by regression analysis for a model that includes working memory and a model that does not include working memory.

## Chapter Two – Review of the Literature

The literature supporting this study will be presented in several sections. The first section describes auditory skills that affect speech understanding: audibility, frequency resolution and temporal processing. In addition it will include the effects of hearing loss on speech perception, particularly when listening in noise. The next section reviews the role of cognition in hearing and its effect on speech perception. Working memory is described in this section since it is a key cognitive process important for understanding speech. The third section will explore general aural rehabilitation options for individuals with hearing loss including amplification and auditory training. The discussion includes, the overall incidence and prevalence of hearing loss and HA users in the United States and the general need for rehabilitative options to improve outcomes. The fourth section provides a general description of current outcomes with amplification within the domains of perceptual benefit and quality of life. Issues related to HA acclimatization are addressed in this section as well. The fifth section addresses the role of plasticity in relation to hearing loss and amplification. This is important because the training component in this study relates to plasticity of the auditory system beyond amplification. In addition, the concept of plasticity provides a rationale for including both new and experienced HA users based on potential differential effects that may be observed between groups. Finally, the history of auditory training, current auditory training programs and a summary of the evidence supporting its use is reviewed. The relevance of each section to the present study is discussed.

### Understanding Speech and the Effect of Hearing Loss

#### *Audibility*

It is widely known that human hearing sensitivity extends across a broad frequency range from 20 to 20,000 Hz (Yost, 2000). Audibility refers to the minimum sound pressure level required to detect these frequencies. The question regarding how much of that frequency range must be audible for understanding speech has been extensively examined. Much of the early work on speech recognition was conducted during the 1930's and 1940's at Bell and Haskins Laboratories as it applied to telephone

and information transmission systems (Pickett, 1980). In general, early experiments involved the use of filtered speech tasks where the percentage of correct words was recorded. For example, in the seminal work of French and Steinberg (1947), listeners heard sentences and words through high and low pass filters. These filters were devices that respond to only certain frequencies of a speech signal. When listening through such filters, listeners hear either low or high frequency regions of the speech stimulus respectively. By manipulating the cut-off frequency of these filters, researchers could systematically present portions of the speech signal which allowed them to determine which portions were the most important for speech recognition. Using this methodology, French and Steinberg first divided the speech signal into two “bands” and concluded that half of the speech information for nonsense syllables resided above 1800 Hz and half below 1800 Hz.

Later research, however, determined that the information transmission mid-point varied according to the amount of redundancy contained in the speech signal (Bell, Dirks, & Trine, 1992). For example, sentences are inherently more redundant because a listener does not have to hear every single word to understand its meaning. Therefore, when sentences, rather than nonsense syllables were presented, the actual mid- point was lower. By further manipulation of the cut-off frequency of filters, French and Steinberg (1947) determined that any given speech signal could be divided into twenty “critical” bands for understanding speech. For example, the first band represented frequencies in the range of 250 to 375 Hz, while the twentieth band represented frequencies in the range of 5720 to 7000 Hz. As an increasing number of bands became audible to listeners, speech recognition improved (French & Steinberg, 1947). Furthermore, French and Steinberg concluded that for optimal speech recognition in quiet, frequency information must be audible up to 3000 Hz. While important information for phoneme identification is available above 3000 Hz, this information becomes redundant in a highly contextualized speech identification task.

*The effect of hearing loss on audibility.* In individuals with sensorineural hearing impairment, the loss of high frequency information is commonly observed clinically. This loss of frequency sensitivity reduces the number of critical bands that are audible and appears to adversely affect speech understanding (Rankovic, 1998). By providing

high frequency amplification for these individuals, speech recognition typically improves for persons with hearing losses less than or equal to 60 dB HL (Hogan & Turner, 1998). In this study, participants with high frequency hearing loss repeated nonsense syllables and gradually received successive “bands” of speech information. They concluded that each successive high frequency band increased the amount of speech that was audible and thus improved listeners’ speech recognition. Interestingly, Hogan and Turner also reported that for individuals whose losses exceeded 60 dB HL, there was virtually no additional benefit from increased high frequency audibility. One could conclude from these studies that individuals with hearing loss will present with poorer speech recognition because much of the speech signal is not audible. However, when high frequency audibility is provided, efficiency in using high frequency spectral information decreases with increasing hearing loss. In fact, it is widely supported that persons with similar hearing losses may present with very different speech recognition abilities (Plomp, 1978; Preminger & Wiley, 1985; Crandell, 1991). These findings may be key to the variable outcome in performance often reported by HA users (Humes, 1991), especially when listening in noise.

### *Understanding Speech in Noise*

Clinical experience and research widely support the notion that the primary complaint of persons with sensorineural hearing loss today is listening in noise (van Tasell, 1993; Nabelek, Freyaldenhoven, Tampas, Burchfiel, & Muenchen, 2006; Takahashi et al., 2007). Interestingly, such clients often present with *worse* speech recognition ability than predicted based on audibility (e.g. pure tone hearing sensitivity) alone (Kamm, Dirks, & Bell, 1985). In a review article, Van Tasell (1993) described the effects of noise in both normal hearing and mild hearing loss listeners. While both groups scored well when speech was presented in quiet, when additional noise was present, scores plummeted for listeners with hearing loss. Such findings suggest that such reductions in speech understanding cannot be explained by loss of hearing sensitivity alone. In a classic description of the communication challenges faced by persons with hearing loss, Plomp (1986) proposed that hearing losses are a composite of both an “attenuation factor” and a “distortion factor”. One method used to illustrate how these

distortion effects extend beyond simple hearing loss was to compare speech recognition among adults with hearing loss and normal “masked” listeners (Needleman & Crandell, 1995). Scores for sentence recognition in noise for the persons with hearing loss were significantly worse than for those with the simulated hearing losses. The effect of such distortion is that when listening in noise, persons with hearing loss require a more favorable signal to noise ratio (SNR) so that the signal is louder than the background noise (Plomp, 1986). Generally, persons with normal hearing require a +2 dB signal to noise ratio for 50% recognition of words in sentences while persons with hearing loss need a +8 dB signal to noise ratio (Killion, 2002). While hearing aids compensate for loss of hearing sensitivity, they cannot compensate for this needed and more favorable SNR, since they amplify both the speech and background noise. Some researchers have therefore suggested that a metric of speech in noise (or babble) may be useful for rehabilitation purposes (McArdle, Wilson, & Burks, 2005). Specifically these authors suggest that SNR loss may be helpful in the selection of the most appropriate amplification options or to document functional communication abilities specific to listening in noise. In the present study, the LACE training program uses fluctuating levels of multi-talker background babble in the training tasks. While individual differences in speech recognition ability in noise among participants is anticipated (Crandell, 1991; Cord, Leek, & Walden, 2000), it seems reasonable to hypothesize that SNR loss should improve in persons who participate in the training groups compared to those who do not.

### *Differential Frequency Sensitivity*

Clinically, it is not uncommon to observe that even when sounds are audible for patients with hearing loss, they continue to have difficulty discriminating between them. This ability to detect differences between frequencies is often referred to as differential frequency sensitivity (Yost, 2000) and refers to the magnitude of change required for a listener to report a just noticeable difference (JND). This task is accomplished by presenting two consecutive tones and measuring the smallest change required for the listener to detect a difference. Although this idea was originally described by Weber in 1834 in relation to perception of weight (Gescheider, 1997), later experiments were conducted in hearing (Wier, Jesteadt, & Green, 1977). Wier and colleagues concluded

that the minimum amount of change in frequency required to detect a JND actually varied across frequencies and was a function of the stimulus frequency. These functions were consistent with estimates originally described by the Weber function. Specifically, Wier and colleagues found that as frequency increased (over 1000 Hz), larger changes in frequency were required to detect a difference. In persons with sensorineural hearing loss, poorer frequency resolution is often reported (Turner & Nelson, 1982; Freyman & Nelson, 1991) meaning that a much larger JND is required to detect differences between frequencies.

*The effect of hearing loss on differential frequency sensitivity.* Differential frequency sensitivity appears to be an important skill related to speech understanding because listeners must often make fine frequency discriminations to distinguish similar sounds between words such as in “me” versus “knee”. Zeng and Turner (1990) measured syllable identification in both normal hearing adults and adults with hearing loss, for four phonemically similar consonant-vowel syllables: see, fee, thee and she. They chose these sounds because the fricative sounds (i.e. /f/, /s/, /ð/, /ʃ/) are particularly difficult to understand for persons with high frequency loss. However, even when the frication portion of the sound was made audible to listeners, listeners still had difficulty discriminating these sounds. The authors concluded that such difficulties in speech recognition are not simply related to sensitivity of sound, but also related to reductions in discrimination skills needed to help listeners identify such similar consonant-vowel combinations. These findings support the idea that listeners with hearing loss may have difficulty discriminating differences between sounds even if sounds are audible.

#### *Temporal Processing and Temporal Resolution*

Temporal processing of acoustic information is also important for understanding speech because a listener must be able to follow rapid changes in timing between speech sounds (Moore, 2003). Such a skill is important for perception because speech sounds fluctuate in duration both within and between words. A specific type of temporal processing is temporal resolution which can be defined as the smallest difference between two sounds that a listener can detect (Shinn, Chermak, & Musiek, 2009). Deficits in temporal resolution have been linked with deficits in speech understanding (Dreschler &

Plomp, 1980,1985) and are thought to be poor in older listeners compared to younger listeners (Gordon-Salant & Fitzgibbons, 1999). These researchers have reasoned that people with hearing loss cannot take advantage of the short temporal gaps that occur when listening to speech amid a background of other talkers. Temporal resolution has been studied using a broad array of methodological approaches for both speech and non-speech stimuli (Letowski & Poch, 1996; Gordon-Salant & Fitzgibbons, 1999; Phillips, 1999). One approach to study temporal resolution uses compressed speech (Jenstad & Souza, 2007). In this study, time compression is used to speed the rate of a speech signal. This technique systematically removes segments and pauses from the speech signal, yet preserves the original signal's overall pitch and prosody. Compression rates are used to describe the extent of temporal compression applied to the signal. A signal with a 40% compression rate would be perceived as slower than a signal with a 70% compression rate (Vaughan, Storzbach, & Furukawa, 2006).

*The effect of hearing loss on temporal resolution.* Overall, older adults with hearing loss have more difficulty understanding time compressed speech than younger adults with hearing loss (Gordon-Salant, Fitzgibbons, & Friedman, 2007). Furthermore, as the rate of compression increases, speech recognition decreases, especially for older adults with hearing loss (Gordon-Salant & Fitzgibbons, 1993). Therefore, rapid speech would seem to be an ecologically valid measurement since listeners encounter speech from a variety of talkers who speak at different rates. If increasing the speed of a spoken message through time compression is a drawback for listeners with hearing loss, then training with compressed speech stimuli may be advantageous.

### Understanding Speech and the Role of Cognition

The cognitive movement emerged after the 1950's as a research field whose goal was to understand how the mind is organized (Anderson, 2005). Psychologists wanted to better explain how humans perform complex tasks like speech recognition so effortlessly. One way to describe the underlying framework for evaluating cognitive processes is an information processing approach. This approach assumes that humans process information much like a computer where data are entered, computed, and stored for later retrieval. It also assumes that information is processed in a hierarchical manner with



sensory information being processed from lower to higher structures (bottom-up). Furthermore, higher cortical processing such as word knowledge and expectation influence our cognitive behaviors and is characterized as top-down processing. Thus, cognition is affected by a processing system that flows in both directions. Since information flows in a bi-directional manner, Pichora-Fuller and Singh (2006) suggested that the processing is actually integrated. This distinction is important for audiologists to consider because it highlights that both systems affect speech perception abilities. Furthermore it suggests that clinically we may need to broaden our thinking about higher cognitive functions and how they interact with peripheral hearing and HA performance.

### *Older Adults and Cognition*

Older adults are often the target population to explore the relationship between hearing and cognition, since they often present with reductions in hearing sensitivity and reductions in cognition (Pichora-Fuller et al., 1995; Pichora-Fuller, 2003). Some research suggested that speech recognition in older adults was largely explained by the extent of the peripheral hearing loss (Humes, 1996). However, such early efforts were based on overall intelligence tests (Pichora-Fuller & Singh, 2006) and thus did not examine the role of specific cognitive processes.

To further explore the relationship between speech recognition and aging, a multidisciplinary working group called the Committee on Hearing, Bioacoustics and Biomechanics (CHABA) (1988) was formed. This working group concluded that future research should incorporate the role of cognition to better understand how specific cognitive processes affect speech understanding. Extensive interest in this topic has emerged in the past decade as evidenced by several recent in-depth reviews on the role of auditory and cognitive processing (Baltes & Lindenberger, 1997; Pichora-Fuller & Singh, 2006; Craik, 2007). These reviews suggest that by comparing performance between older and younger adults on specific cognitive processes such as attention, processing speed and working memory, individual differences emerge that further account for speech recognition ability beyond peripheral hearing. Therefore, each of these cognitive processes will be discussed briefly below.

## *Attention*

There are many forms of attention that potentially affect speech recognition. One way to describe these different forms is based on their function. For example, selective attention can be defined as processing some information while ignoring other information, whereas divided attention can be defined as the simultaneous processing of multiple sources of information (Haykin & Chen, 2005). In the auditory domain, both selective and divided attention become important skills when trying to follow a conversation in a noisy environment, which is known as “cocktail party effect”(Alain & Arnott, 2000). In such conditions, multiple sources of noise are vying for the listener’s attention and listeners must select what to attend to and what to ignore.

Cherry’s classic cocktail party studies (Cherry, 1953) used dichotic listening tasks to evaluate selective attention. When listening to two speakers at the same time, a listener could adequately follow a speaker in the “attended” ear and ignore the competing speaker in the “unattended” ear. If asked later about the competing signal, listeners could not identify critical features about the speaker, including the language or even the speaker’s gender. If however, the participants’ own name occurred in the unattended ear, then listeners could identify this information. These results highlighted two important issues that are interrelated; if listeners do not attend to information, they will not process it, however, if the information is meaningful enough, listeners can process it regardless of whether they are attending or not.

*Selective and Divided Attention.* Broadbent (1954) studied both selective and divided attention in a series of classic experiments using dichotic listening tasks. Participants were asked to repeat words in one (selective attention) or both ears (divided attention). Participants were better at identifying sequences of numbers presented to one ear or the other, compared to alternating the sequences of numbers between ears. These findings suggested that only one input could be processed at a time and that some type of filtering occurred that allowed the listener to attend to one input and ignore the other. In addition, Broadbent suggested that such filtering occurred early in the processing stream and was based on the physical parameters (i.e., frequency or intensity) of the signal. He concluded that the unattended sensory channel was essentially turned off so that no further processing could occur. In contrast, others argued that a later filtering effect

actually existed (Deutsch, Deutsch, Lindsay, & Treisman, 1967). Deutsch and colleagues reasoned that all sensory information was processed, but only the most relevant stimuli are processed based on memory and experience

A resolution to this debate was proposed with Treisman's attenuator theory (Treisman, 1969). Treisman posited that selective attention occurs during both early and late processing of incoming sensory information and that an initial phase of selection occurs based on the physical properties of the attended signal. This results in the processing of a stronger stimulus from an attended channel, while a stimulus from an unattended channel is attenuated. Although unattended stimuli are attenuated, they are not completely filtered out as originally hypothesized by Broadbent (1954). This is an important distinction because, if the stimulus is relevant enough (such as a familiar name), it can be processed later, even if the listener is not focused on it. Treisman's attenuator theory incorporated two ideas about the mechanisms of processing which included both signal strength and signal relevance. Thus, the theory that combines both bottom up (signal strength) and top-down (signal relevance) processing seems to have its roots in experimental psychology (Craik, 2007).

*Relevance to Study.* From a communication standpoint, both selective and divided attention tasks are relevant to this study in two ways. First, both types of processing seem to be compromised in listeners with hearing loss (Shinn-Cunningham & Best, 2008). In this review, the authors explain that with impaired auditory function, physical features of the signal (frequency, duration, intensity) are not encoded peripherally. This in turn hinders auditory object formation and thus impairs their ability to filter out competing signals. Thus, it appears that deficits in the early processing stages lead to later failures in perception. Second, the LACE training program incorporates both a divided attention task (speech in noise) as well as a selective attention task (competing speaker). Since speech recognition appears to involve, peripheral encoding, central processing and cognitive processing components (Pichora-Fuller & Souza, 2003), we are likely training a process. Furthermore, training tasks that focus on these early stages of processing may improve higher level perception. Therefore, it seems important in this study that both types of attention tasks should be trained since evidence suggests that both are important

in the processing for understanding messages, especially in dynamic, real world listening conditions.

### *Working Memory*

Working memory can be described as a temporary storage mechanism that we actively manipulate while solving complex tasks (Baddeley, 1992). Its components include: 1) a central executive functioning mechanism and two subsystems: 2) a visual sketch pad; and 3) phonological loop (Hitch, Woodin, & Baker, 1989). These systems allow us to manipulate and retain small amounts of visual and verbal information for at least short periods of time. The central executive is theoretically in control of both subsystems and therefore responsible for planning, initiating and integrating working memory from both modalities. Therefore working memory is thought to be an important cognitive process that allows us to capture and store ongoing verbal and visual information similar to real time captioning which temporarily displays information before it is stored by a computer.

A preserved working memory is thought to be crucial for understanding speech and language (Daneman & Carpenter, 1980; Caplan & Waters, 1999). These researchers both highlight the strong correlation between verbal working memory ability and language comprehension. Specifically, persons with a larger working memory typically displays better language processing skills compared to persons with smaller working memory. These findings are logical because in conversation, listeners must briefly hold part of the phonemic content from a word before they hear the ending of the word. Additionally, listeners have to hold the initial parts of a phrase before hearing the remaining portions. Furthermore, performance on working memory tasks have recently been shown to predict performance on a wide variety of tasks including reading comprehension (Daneman & Carpenter, 1980), performance on the Stroop task (Kane & Engle, 2003), and even the onset of Alzheimer's disease (Rosen, Bergeson, Putnam, Harwell, & Sunderland, 2002).

*Measurement of working memory.* Working memory can be measured by performance on span-loaded tasks (e.g., forward digit span, backwards digit span, reading span), where participants have to perform a dual-task related to comprehension and recall

of items presented. For example, in the Reading Span Test, participants read a sentence, judge its meaning and also recall the final word of the sentence (Daneman & Carpenter, 1980). Some researchers have suggested working memory has a limited capacity. Miller (1956) suggested that this capacity was represented by the “magical number seven” (plus or minus two). Interestingly, this metric has held steady over five decades of experimental research across several different sensory systems (Baddeley, 1994). For example, in a typical memory span task, participants generally recall about five unrelated words from a word list (Baddeley, Thomson, & Buchanan, 1975). Given that working memory appears to be a capacity limited mechanism, when speech becomes difficult to understand, the size of working memory may also affect how well persons perceive speech. In individuals with hearing loss, there is a strong correlation between the size of working memory and perceived listening effort (Lyxell, Andersson, Borg, & Ohlsson, 2003). Specifically, the smaller the size of working memory, the greater the perceived effort required when listening in noise.

*Factors affecting working memory.* Baddeley (1992) proposed that we manipulate information by essentially reciting it to ourselves, which he termed a sub-vocal rehearsal routine. If this is true, then an individual who can rehearse more quickly should present with more efficient working memory. Here the idea of processing speed seems to be intricately linked with working memory and will be discussed in greater detail in the next section. Of additional concern for individuals with hearing loss is the phonological similarity effect (Baddeley, 1992). In this review, Baddeley reported that recall of unlike words is easier than similar words. In persons with hearing loss, words that sound similar can be easily confused. While these confusions are often attributable to spectral deficits (Carney & Nelson, 1983), it is possible that some of the variance may be attributable to the additional time and effort allocated to discriminating sounds, which in turn reduces the amount of time listeners have to get items into working memory.

Pichora-Fuller, Schneider and Daneman, (Pichora-Fuller et al., 1995) examined age-related declines in working memory in older adults while controlling for hearing loss. These authors measured sentence recognition in noise for both older and younger adults using both “high context” and “low context” sentences. Hearing levels for both groups were essentially normal. Listeners were asked to identify the final word of sentences in

noise using an *n-back* working memory task. An *n-back* task often requires the participant to recall not just the last item presented, but several previously presented items as well. Researchers found that both older and younger adults with normal hearing performed worse with increasing levels of noise. However, older listeners recalled fewer final words than younger listeners even though they could hear and repeat the words correctly. This illustrates that older adults even without hearing loss have greater difficulty integrating words in connected speech for comprehension. Cognitive processes like working memory likely to contribute to the reduction in speech comprehension in older adults as well as persons with hearing loss.

### *Processing Speed*

One aspect of aging is a reduction in general processing speed (Salthouse, 1996; Baltes & Lindenberger, 1997). Many studies have used reaction time as an indicator of slower processing in older adults (Salthouse & Coon, 1993; Gottlob, 2006). While reaction times are slower in older adults, reduced processing speed throughout an information network could alter the efficiency of several cognitive mechanisms. For example, comprehension could be adversely affected by a reduction in how quickly information can be rehearsed (Sanders, Murphy, Schmitt, & Walsh, 1980). The speed at which an individual can shift focus is another behavior that may be affected by processing speed (Salthouse, 1998). For example, when in group conversations, switching attention from one speaker to the next is often necessary. Finally, the rate of execution of bottom-up and top down processing could also affect comprehension (Craik, 2007).

To study processing speed, Tun, Wingfield, Stine and Meccas (1992) used a divided attention task paradigm where participants were required to listen to sentences at different speech rates while engaged in a picture identification task. They measured recall ability in both older and younger adults. Although both older and younger adults performed worse on the speeded sentence task, absolute performance was worse for older adults compared to younger adults on all tasks. Tun and colleagues concluded that these findings illustrated that processing speed affects comprehension for older adults.

*Relevance to Study.* The discussion above highlights how working memory and processing speed seem keenly relevant to the present study. Since most HA users are older adults over the age of 65 (Kochkin, 2005), they present with both hearing loss and age-related declines in working memory (Bopp & Verhaeghen, 2005). In this population, listening in noise remains their primary complaint (Takahashi et al., 2007). In this large, longitudinal study, even though amplification improved audibility of speech in quiet, listening in noise remained difficult. Since understanding in noise is more difficult, it generates additional cognitive load for listeners, and therefore requires more effort (Pichora-Fuller et al., 1995). This additional cognitive load may adversely affect such processes as working memory because the resources typically allocated to working memory must now be re-allocated to listening in noise. Therefore, it is not surprising that some researchers have shown a strong correlation between speech recognition in noise and cognitive function as evidenced by working memory capacity and verbal information processing speed (Lunner, 2003).

Working memory and processing speed will be incorporated in this study in several ways. First, the LACE training program primarily uses training tasks presented in noise. This condition can best be described as “speech babble” where many persons are speaking simultaneously. Training on tasks in this condition may make listening in noise less effortful, and therefore participants should demonstrate improvements in speech recognition.

Second, since individual differences in working memory are likely to exist among participants, this variation may explain individual differences in performance after training. Specifically, individuals with higher cognitive ability in working memory may obtain more benefit from training because of the previously discussed relationship between perceived effort and size of working memory (Larsby, Hallgren, Lyxell, & Arlinger, 2005). However, the opposite may also be true. Individuals with lower cognitive ability may actually benefit more from the training because they have more potential for improvement.

Third, the LACE™ training program incorporates a rapid speech task that requires listeners to identify “compressed” speech where the pauses and hesitations have been removed. While the average rate of speech (American English) is 140 words per

minute (Fairbanks, Guttman, & Miron, 1957), listeners often encounter individuals who speak at different rates. Normative studies have shown that as time compression is increased, word recognition is decreased (Calearo & Lazzaroni, 1957). In adults with hearing loss, significant reductions in speech recognition were observed with increasing compression rates compared to normal hearing listeners (Kurdziel, Rintelmann, & Beasley, 1975). However, dramatic reductions in comprehension were not observed until compression ratios exceeded 70% of the typical speaking rate. In the present study, a compression ratio of 45% used with word recognition stimuli should challenge the participant, but not exceed known compression rates that result in significant deleterious effects.

Finally, cognitive ability may be a predictor of overall success with amplification as reported by Gatehouse, Naylor and Elberling (Gatehouse, Naylor, & Elberling, 2003). In this seminal study, participants with faster processing speeds derived greater benefit from signal processing strategies that used fast time constraints in their hearing aids. In contrast, participants with slower processing speeds benefited more from signal processing strategies that used slower time constraints. An extension of this idea can be applied to the research questions central to this study. Individuals with higher cognitive ability (faster processing speeds and greater capacity for storage) may benefit more from training than those with lower cognitive ability. However, it is not known what effect cognitive ability has on training outcome. Therefore, a metric that reflects working memory and processing speed will be included as a possible predictor variable related to performance after training.

## Aural Rehabilitation

### *Definition and Description*

Aural Rehabilitation (AR) can be broadly defined as an intervention that is “a process” for the purpose of alleviating any insufficiencies in understanding real world speech caused by hearing loss (Boothroyd, 2007). According to Boothroyd, inherent to this process are several components that may need to be addressed which include: 1) sensory management; 2) instruction; 3) counseling and 4) perceptual training;. Each



component is comprised of different activities which can be pursued as a means to improve functional listening and overall communication ability. For example, in sensory management, an appropriately fit HA should offset the spectral deficits associated with a high frequency hearing loss, making speech audible. However, some individuals may still have difficulty listening in noise and may benefit from using accessory devices to provide improved acoustic access for participating in noisy conditions. Instructions are provided for clients about how devices work. They are often presented both orally and in writing. Group or individual counseling may be needed to address psychosocial issues that involve social emotional issues related to the hearing loss or identify communication strategies to enhance speech understanding. Finally, additional perceptual training may be necessary to systematically re-teach an individual to make perceptual distinctions about sounds to enhance their listening abilities (Schow & Nerbonne, 2007).

While, conventional dispensing programs typically include instruction with their sensory management services, they often do not include perceptual training due to lack of time and reimbursement issues. Auditory training, the subject of this dissertation, can be considered a form of perceptual training. Auditory training is a direct remediation approach which may be formal or informal, but is structured around various types of training stimuli, targeted at specific skills, which vary in level of difficulty (Robinson & Summerfield, 1996).

### *Incidence and Prevalence of Sensorineural and HA use*

Over 29 million Americans are estimated to present with significant hearing loss (Agrawal, Platz, & Niparko, 2008). Across the lifespan hearing loss is present in approximately 30% of adults between the ages of 50-65 and up to 50% of adults over the age of 75 (Adams & Marano, 1995). Due to the increasing age of the population in the United States, the number of persons with hearing loss is projected to rise. While hearing loss is the third most common chronic condition in adults over the age of 65 after hypertension and arthritis (National Center for Health Statistics, 1990), current HA use is considered low (Popelka et al., 1998). In this large epidemiology study on hearing loss, only 14% of adults with deficits actually reported using a hearing aid. Several factors

such as cost, stigma, cosmetics, lack of perceived benefit and concern regarding handling technology have all been identified as factors related to the low compliance of HA use in adults (Franks & Beckmann, 1985; Garstecki & Erlen, 1998; Kochkin, 2002). Together, these demographic patterns suggest that there is tremendous room for improvement in the overall use of sensory devices.

### *Access to Aural Rehabilitation*

AR was the cornerstone of early clinical and research efforts to improve listening ability in veterans returning from WWII (Schow & Nerbonne, 2007). Some researchers have reported reduced HA return rates (Northern & Beyer, 1999) and increased satisfaction among individuals who receive AR (Wayner, 2005). Still others have reported that the quality adjusted life year (QALY) is significantly better when individuals receive AR in combination with their HA compared to receiving their HA alone (Abrams, Chisolm, & McArdle, 2002). Such findings suggest that AR is not only essential to improved communication function, but it is also cost-effective. However, as audiology evolved and technology advanced, we have migrated away from these rehabilitative roots in hopes of finding the ideal technological solution for our clients. Many clinicians focus on the dispensing of hearing aids as evidenced by the large proportion of audiologists in private practice (Schow & Nerbonne, 2007). As such, even though audiologists are aware of the benefits of AR programs (Hawkins, 2005), access to such programs for consumers is limited (Prendergast & Kelly, 2002).

*Relevance to study.* Audiologists are often faced with trying to re-adjust hearing aids for new users. Such “tweaking” often does not result in any real improvement in HA performance (Cunningham, Williams, & Goldsmith, 2001), yet clinicians may continue to adhere to such strategies because they currently have limited alternative interventions for improving functional hearing. By placing the bulk of our rehabilitative efforts in technology, we have neglected the additional benefit of alternative forms of rehabilitation for our clients such as auditory training or group therapy. Therefore AR faces unprecedented opportunity to explore new home training interventions for individuals with hearing loss. AR services such as auditory training, may be a long overlooked

puzzle piece that has the potential to improve overall performance and satisfaction with hearing aids (Kricos & McCarthy, 2007).

## Outcomes with Amplification

### *Benefits and Limitations of Amplification*

HAs are the primary intervention that audiologists consider to offset deficits from a hearing loss. Extensive research documents the widespread benefits of this type of sensory management (Plomp, 1978; Fujikawa & Owens, 1979; Davis & Haggard, 1982; Humes, 1991; Bentler, Niebuhr, Getta, & Anderson, 1993; Jerger, Chmiel, Florin, Pirozzolo, & Wilson, 1996; Turner, 2006). Overall, this research illustrates the benefits from amplification in easy listening conditions (Shanks, Wilson, Larson, & Williams, 2002), reduction in perception of disability (Newman, Weinstein, Jacobson, & Hug, 1990; Marttila & Jauhiainen, 1996; Saunders & Forsline, 2006), and improved communication function and quality of life (Chisolm et al., 2007; Takahashi et al., 2007). However many individuals who use hearing aids still encounter difficulties while listening in noisy or reverberant conditions (Bentler et al., 1993; van Tasell, 1993). Satisfaction with hearing aids has been widely documented (Cox & Alexander, 1995, 1999) and seems to be affected by cost and perceived negative attributes of HAs, such as listening in noise (Cox & Alexander, 2001). Furthermore, individual variability in performance with HAs despite similar degree of hearing loss has been reported (Gordon-Salant, 2005).

### *Acclimatization*

The term “acclimatization effect” was first described by Gatehouse (1992) in a study on four adults with sensorineural hearing loss and monaural HA use. In this study, Gatehouse observed that acclimatization was a process whereby individuals gradually became accustomed to amplification. He reported that perceptual changes following HA fitting can be measured immediately after fitting, but continue to improve up to approximately twelve weeks. Therefore, maximum performance after HA fitting may not be obtained until acclimatization is complete. An in-depth review on this topic has been published (Turner, Humes, Bentler, & Cox, 1996) to answer the question about how HA benefit changes over time. Turner and colleagues concluded that while mixed results

about the precise time frame over which acclimatization occurs, its nature cannot be denied. For example, they found some research that reported minimal acclimatization effects (Bentler, Niebuhr, Getta, & Anderson, 1993) and other research reporting that acclimatization effects could be observed out to 12 or 18 weeks (Cox & Alexander, 1992; Gatehouse, 1993). A more recent study suggested that significant improvements in speech intelligibility may be observed in adult HA users even up to six months (Reber & Kompis, 2005).

*Relevance to Study.* While the findings outlined above highlight the overall benefit of HAs, they also point to the reductions in performance experienced by some users. These deficits may be responsive to training with a program that specifically targets listening in noise. While the existence of acclimatization appears to be widely acknowledged in this literature, it is important for audiologists and researchers to be cognizant of its effects when reporting any benefit of amplification. Therefore, new HA users in this study began training 4-weeks after the initial fit of the HA to allow for gradual adjustment to the hearing aid. In addition, since acclimatization may extend beyond the first 4-weeks after a HA fitting, a control group of new HA users was also formed to control for such effects.

## Role of Plasticity

### *Plasticity Defined*

Neural plasticity is the capacity of the brain to modify its organization (Bavalier & Neville, 2002) and is the underlying framework in rehabilitation science today. This growing body of literature suggests that the brain is capable of reorganization throughout the lifespan. Such reorganization is widely attributed to two mechanisms: 1) the unmasking of pre-existing neural connections; and/or 2) the establishment of new neural connections (Pascual-Leone, Amedi, Fregni, & Merabet, 2005). One classic illustration of plasticity was observed in adult owl monkeys following amputation of an index finger (Merzenich & Kaas, 1982). These researchers found that when deprived of afferent input from the missing index finger to the somatosensory cortex, unique reorganization patterns were observed. Rather than becoming dormant after amputation, the deprived cortical

areas became responsive to regions of the body that were adjacent to the lesioned digit. This expanded pattern cortical representation is evidence of plasticity.

### *Plasticity in the Auditory System*

Similar plastic changes have been observed in the auditory system across the lifespan and are summarized in two excellent in-depth reviews (Palmer, Nelson, & Lindley, 1998; Syka, 2002). Several studies discussed in these reviews have examined the effects of both early and late cochlear damage, as well as the change in performance observed after experience with sensory devices such as hearing aids or cochlear implants. One of the conclusions of the Syka (2002) review is the promising role of intensive auditory training paradigms in combination with sensory devices because of the potential training has in contributing to auditory plasticity.

A useful model to categorize the various forms of auditory plasticity was described by Willot (1996). Willot suggested that three forms of plasticity are relevant in describing aural rehabilitative efforts and include: 1) deprivation from reduced sensory input; 2) compensation following use of sensory systems such as hearing aids or cochlear implants; and 3) learning related which occurs after training. Therefore, the literature relevant to these forms of plasticity will be discussed below.

*Deprivation.* A trademark characteristic of the auditory system is its precise tonotopic organization. Highly organized frequency patterns are derived from the mechanical response of the cochlea, and similar organization is observed throughout the central auditory nervous system. For example, in the primary auditory cortex, neurons that are characteristically tuned to either low or high frequencies are located rostrally and caudally respectively. This organization can be disrupted in the presence of significant hearing loss as evidenced by silent regions of neural activity that were observed from the cochlear nuclei of deaf cats (Koerber, Pfeiffer, Warr, & Kiang, 1966). Similar immediate effects were observed at the level of primary auditory cortex in unilaterally deafened guinea pigs (Robertson & Irvine, 1989) and in cats (Rajan, Irvine, Wise, & Heil, 1993). However, several months later, reorganized tonotopic maps were observed. Neurons that had previously been unresponsive, now demonstrated nearly normal thresholds to different characteristic frequencies that were adjacent to the area of the cochlear that was

damaged. In summary, these animal studies across a number of species, consistently illustrate how reductions in hearing affect tonotopic reorganization both immediately and over longer durations of time.

*Compensation with Sensory Devices.* The behavioral change observed in individuals receiving cochlear implants is empirical evidence that the auditory nervous system can adapt to an artificial signal provided through sensory devices. The effects of cochlear implantation in animals with congenital deafness has been studied (Kral, Hartmann, Tillein, Heid, & Klinke, 2002). Here, electrophysiological changes were measured following cochlear implantation in deaf cats. Specifically, they observed enhancements in the pattern and timing of waveforms associated with auditory evoked cortical potentials after cochlear implantation in both young and old cats. Not surprisingly, smaller cortical changes were observed in older cats compared to younger cats. This is consistent with the concept of a critical window for intervention for children. In general, higher performance is observed in children who receive cochlear implants early compared to those who receive them later in childhood (Sharma, Dorman, & Spahr, 2002).

Examination of the role of plasticity following HA use in humans has been challenging because it is more difficult to examine the precise nature and extent of sensorineural damage. However, one method adopted to examine plasticity is within ear changes following monaural HA fittings compared to the non-fit ear (Munro, Walker, & Purdy, 2007). While improvements in auditory perception are often observed in the amplified ear, degraded speech recognition performance is observed in the non-amplified ear (Silman, Gelfand, & Silverman, 1984). These findings provide evidence for clinicians that the use of amplification may prevent further effects of deprivation. More recently the effects of amplification were examined by indirectly measuring auditory cortical activity with neurophysiologic measures (Korczak, Kurtzberg, & Stapells, 2005). In adults with moderate to profound hearing losses, Korczak and colleagues examined the effects of HA use on auditory event related potentials (AERP). Overall improvements were reported in the detectability of all AERP's in the aided condition compared to the unaided condition in response to speech stimuli (/ba/ and /ga/).

Both sets of evidence from humans and animals measuring plasticity following the use of sensory devices demonstrate the potential for central auditory nervous system reorganization, even in adults. The evidence supporting plastic changes following HA fittings is relevant in this study because it highlights the importance of using a control group of HA users only.

*Training.* Adaptations within the central auditory nervous system also occur in response to training. Seminal research related to auditory plasticity was illustrated by the training of owl monkeys on a frequency discrimination task (Recanzone et al., 1993). Adult monkeys showed reorganization of tonotopic maps in primary auditory cortex after several weeks of training. Additionally, improvements in perceptual abilities were obtained only for the frequencies on which the monkeys were trained. In humans with normal hearing, similar response patterns have been obtained following auditory training. Discrimination training targeted to improve listeners' ability to identify differences between synthetic variations of the phoneme /da/, resulted in improved post training scores in adults (Tremblay, Kraus, Carrell, & McGee, 1997). This group also found significant changes in the magnitude of the mismatched-negativity (MMN) waveforms after training. These findings suggested that neural changes had occurred along with the measured behavior changes giving the authors confidence to conclude that plasticity is possible even in mature adults. Animal studies have further examined the effects of auditory training in combination with sensory devices. When deaf white cats were initially implanted they showed behavioral responses to sound and evidence of cortical tonotopic re-organization (Kretzmer, Meltzer, Haenggeli, & Ryugo, 2004). After training, field potentials showed enlarged cortical regions in both the ipsilateral and contralateral cortices (Kral et al., 2002; Kral, Tillein, Heid, Hartmann, & Klinke, 2005).

*Relevance to study.* Several concepts from the literature on neural plasticity are relevant to the present study. First, these studies demonstrate that dynamic mechanisms exist within the auditory system and are susceptible to change. This argues against the conventional idea of a hardwired system for adults with hearing loss. Even adults who are experienced HA users may be able to demonstrate change after training. Second, the use of intensive, activity dependent auditory training paradigms in combination with sensory devices offers individuals additional hope for improved outcomes beyond the use of a

sensory device alone. Therefore the training effects in both new and experienced HA users will be analyzed in this study. It is possible to infer from the above discussion that new HA users may derive more benefit from training in comparison to experienced HA users.

## Auditory Training

### *Definition and Description*

The main focus of the present proposal is on auditory training in adult HA users. Auditory training can be described as an intervention where listeners are taught to make perceptual distinctions about sounds which are presented systematically (Schow & Nerbonne, 2007). As described earlier, programs are structured using varying types of stimuli, targeting specific listening skills while varying the level of difficulty (Robinson & Summerfield, 1996). Traditional programs usually take place in a one-on-one setting. Generally, drill like activities using targeted syllables (/bi/ vs /bu/) or minimal pairs of words (cart vs card) are described as “analytic”. In contrast, sentence completion tasks are considered “synthetic” (Schow & Nerbonne, 2007). Table 2.1 shows the range of speech stimuli used in auditory training.

### *History of Auditory Training*

Early efforts to use auditory training were primarily targeted to stimulate speech production in children with deafness (Wedenberg, 1951). However, auditory training for adults has its roots with military personnel returning home following WWII. Traditional auditory training programs were developed through the Veteran’s Administration to use with an adult population (Schow & Nerbonne, 2007). Early on, Carhart (1960) promoted the concept that training should be targeted at teaching individuals how to maximize their residual hearing. He proposed that teaching should be centered around a systematic presentation of auditory skills that range from simple to more complex tasks (Erber & Hirsh, 1978). For example, detection tasks are simpler in comparison to comprehension tasks. In addition, Carhart (1960) proposed that training should incorporate stimuli that vary in difficulty from simple (syllables, words) to more difficult (phrases, sentences and connected discourse). A matrix showing the auditory skills and variable stimuli that are used during training is shown in Table 2.1



Table 2.1. Auditory Skills Matrix (Erber and Hirsh, 1978)

	<i>Stimuli</i>				
	Syllables	Words	Phrases	Sentences	Connected Discourse
<i>Auditory Skills</i>	Detection (presence/absence)				
	Discrimination (same/different)				
	Identification (recognition)				
	Comprehension (understanding)				

More recent approaches to auditory training suggest that an eclectic method of auditory training with adults be used where both synthetic and analytic activities are presented (Schow & Nerbonne, 2007). Speech recognition can be taught using an analytic (bottom-up) approach where progressively finer acoustic contrasts between vowels and consonants are presented within words and syllables. For example, a listener may be asked to determine if two words are the same or different (shop and stop). These two words differ in both place and manner of articulation. To make the listening task more difficult, words that differ only in manner of articulation (shop vs chop) would be presented. In contrast, speech comprehension is taught using a top down (synthetic) approach. This method allows listeners to take advantage of contextual and syntactical cues provided by connected speech. Common phrases, sentences and even short paragraphs are presented for listeners to repeat, complete or answer.

#### *Efficacy of Auditory Training in Adult HA Users*

Several researchers have examined the effects of traditional auditory training in HA users (Bode & Oyer, 1970; Walden, Erdman, Montgomery, Schwartz, & Prosek, 1981; Montgomery, Walden, Schwartz, & Prosek, 1984; Rubinstein & Boothroyd, 1987; Kricos, Holmes, & Doyle, 1992; Kricos & Holmes, 1996). Generally participants in these

studies showed improved performance on the speech tasks on which they were trained. However, significant variability was reported, which makes interpretation about the efficacy of auditory training difficult to ascertain.

*Computerized auditory training.* More recently, several researchers have examined the effects of computerized auditory training programs in adults with hearing aids and cochlear implants (Burk, Humes, Amos, & Strauser, 2006; Sweetow & Sabes, 2006; Miller, Watson, Kistler, Wightman, & Preminger, 2007; Sweetow & Sabes, 2007). Overall, these studies show renewed promise for the benefits of auditory training.

An enlightening series of experiments on auditory training were conducted at Indiana University using laboratory based computer training programs. These experiments, conducted in highly controlled environments, have revealed several interesting observations about training paradigms and choice of training stimuli. For example, Burk and colleagues (2006) provided training using single words with a single female talker over nine to fourteen days for both older and younger adults. They found that while listeners improved in their word recognition ability, there was minimal generalization to understanding of novel sentences. In another experiment, Burk and Humes (2007) examined the effect of training rate using lexically hard words from multiple speakers. One group of young adults received 5 to 12 hours of training, and the other group received 15 to 20 hours of training. Interestingly, word recognition did not improve for those who underwent the extended training, but sentence recognition did improve (Burk & Humes, 2007). In a later repeated measures design, eight older adults with hearing loss completed a twelve week training program using both hard and easy words (Burk & Humes, 2008). Follow up testing showed large improvements (40-50%) above pre training baseline scores for word recognition ability. In contrast, sentence recognition (using key words from the training lists) only improved by 4-8%. Burk and colleagues concluded that generalization to sentence recognition was minimal because word training was too limited when considering the infinite number of possible sentence combinations. To address this issue, another training study was conducted using both frequently occurring words and common phrases with older adults (Humes, Burk, Strauser, & Kinney, 2009). Eighty percent of older adults improved on most or all of the post training measures including word and sentence recognition tasks.

Sweetow and Sabes (2006) described results from their multi-site study with the LACE™ computer training program. This study examined training benefits in HA users with an average of 5.3 years (range: 6 months to 44 years) of HA use. After 4-weeks of training, the trained group improved on both computer generated and standardized outcome measures. Trained participants obtained an average improvement in SNR of 2.2 dB at 45 dB HL and 1.5 dB at 70 dB HL. In a follow-up study, Sweetow and Sabes (2007) examined factors that predicted outcome from training. In general they determined that persons who had the most to gain improved the most ( $r = .43$ ). This meant that persons with better function before training actually improved the least. No HA aid users with less than six months of use were included in the Sweetow and Sabes study.

Unfortunately, the lack of unequivocal evidence leaves the impression that adults will adapt over time after receiving HAs and that training is not needed. Furthermore, clinicians in busy HA dispensing centers have limited time in which to provide auditory training. These time pressures, along with the limited research supporting the efficacy of auditory training result in a paucity of learning opportunities for adults.

Stecker and colleagues (2006) used a home computer program with both new and experienced adult HA users. The program focused on syllable identification, via an adaptive training regimen which occurred five days per week for eight weeks. Participants in both an immediate and delayed treatment group showed similar improvement in syllable identification (10.6% and 8.8% correct respectively), suggesting that even the participants whose training was delayed were able to receive benefit. New users had no HA experience before training began, while experienced users had an average of 16 months (range 10-21 months). No comprehensive study to date has compared the benefit of training in both new (less than six months) and experienced (more than two years) HA users. This is an important clinical question so that clinicians can better understand how performance changes over time after training for these two populations.

Recently, Stacey and Summerfield (2008) evaluated the effectiveness of different types of training stimuli using a vocoded speech paradigm. In this method, researchers use a synthesized degraded speech signal to study the effects of frequency resolution on speech recognition (Fu & Shannon, 1999). The speech signal can be manipulated so that

it is “degraded” making it difficult even for normal hearing listeners to recognize. In the Stacey and Summerfield (2008) study, vocoded speech (using words, sentences, and phonemes in nonsense syllables) was presented to normal hearing listeners. After nine training sessions over 2-weeks, they found that overall sentence recognition of vocoded speech improved 5.4% for the word training group, 14.8% for the sentence training group, but only 1.5% for the phonemic training group. This suggests that a sentence based training program may be more beneficial than a word based training program for sentence recognition.

*Listening and Communication Enhancement Training (LACE™)*

As discussed previously, the LACE™ program (Sweetow & Sabes, 2006) is a commercially available training program that adult HA users can use at home. To date, the Sweetow and Sabes study is the only published study that has examined the efficacy of this sentence-based training program. Furthermore, this study focused on the computerized training program format since it was the only format available at the time that the research was conducted. The computerized format requires users to download software to a personal laptop. The training is comprised of twenty lessons that take approximately 4-weeks to complete. An additional aspect of this training program is that performance can be monitored remotely by clinicians via a secure internet server. A newly developed LACE™ DVD format was used in this research. The DVD training is comprised of ten sessions which take approximately 30 minutes per day, five days per week to complete. It is not clear if the improvements observed with the computerized format are similar to the DVD format for LACE™ training. In addition, the shorter version of LACE™ was developed because much of the improvement obtained by participants in the Sweetow and Sabes (2006) investigation occurred within the first half of the training sessions. However, this finding has not been replicated. Therefore, participants in this study were evaluated at both the 2-week and 4-week intervals to determine how performance changed over time. To achieve 4-weeks of training, participants completed ten lessons over the first 2-weeks of training and then repeated the same ten lessons over an additional 2-week training period.

The LACE™ training program was presented to listeners through a DVD player connected to their home television. Listeners actively interacted with the training by using a remote control. Stimuli were presented adaptively so that the training material was neither too difficult nor too easy. For example, if participants answered correctly, the following task would become more difficult. In contrast, if they answered incorrectly, the subsequent task would be easier. As mentioned earlier, participants completed the 2-week training program twice so that the total training time (4-weeks) with the DVD was similar to the total training time used with the computerized program and described by Sweetow and Sabes (2006). Therefore, total training time with the home DVD program was 4-weeks with participants completing twenty sessions of the adaptive training regimen. Assessments occurred at baseline, 2-weeks and 4-weeks after training. The DVD training focused on training across three conditions: speech in multi-talker speech babble rapid speech, and competing speaker. To date, there is no evidence about how effective the training provided via DVD format is for new and experienced HA users alike.

## Chapter Three – Methodology

In the previous chapter, the literature supporting this study and rationale were discussed. The areas addressed in this chapter include: research design, general procedures, selection criteria, description of participants, group assignment, dependent measures, assessment procedures, intervention procedures and plans for analysis.

### *Research Design*

The study was approved by the University of Kentucky Institutional Review Board (IRB). No previous research has been conducted examining the effects of the LACE™ DVD program. Therefore, this research was a Phase I, prospective repeated measures group design (Robey, 2004). The independent variable was the LACE™ home training program accessed at home through a DVD player and television. The dependent variables included measurement of several listening skills (understanding in noise, rapid speech, and competing speaker) measured at baseline, 2-weeks after training and 4-weeks after training.

### *General Procedures*

*Sequence of events for treatment groups.* The sequence of events completed in this experiment for the treatment groups is shown in Figure 3.1. After signing informed consent, baseline testing and program orientation was completed. Next, each participant completed ten sessions of home auditory training. Then, he/she returned for mid-training assessments approximately 2-weeks after baseline testing. After this, each participant was instructed to repeat the same ten sessions of home auditory training. Then, he/she returned for the final 4-week assessment approximately 2-weeks after the mid-training assessment. Thus, persons in the training groups were observed on three occasions during the study. These time-points are referred to as: “baseline”, “2-weeks” and “4-weeks”. Persons in the training groups are referred to as: “New + Training” or “Experienced + Training”.

*Sequence of events for control group.* The sequence of events completed in this experiment for the control group is shown in Figure 3.1. The control group was

comprised of new HA users who did not receive the training. After signing informed consent, baseline testing was completed for each participant in the control group. Follow up testing of control group participants occurred 4-weeks after baseline testing. After the 4-week assessment, participants received the LACE™ DVD training program and were instructed on its use. They were not required to return for follow-up after receiving the training program. Thus, persons in the control groups were observed on two occasions during the study. These time-points are referred to as: “baseline” and 4-weeks”. Persons in the control group are referred to as: “New-Control”.

Baseline speech perception measures were compared with 2-week and 4-week follow-up measures to determine if significant changes occurred following training. In addition to these objective measures, subjective self assessments relating to satisfaction and benefit from the training were analyzed along with perception of communication ability. The repeated visits were included in this design to allow for analysis of performance changes over time. The control group of new HA users was included to compare performance with the HA alone to the new HA users who received the training.

Figure 3.1 Overall timeline of study for treatment and control groups. Upper panel shows timeline for both treatment groups. Lower panel shows timeline for control group.

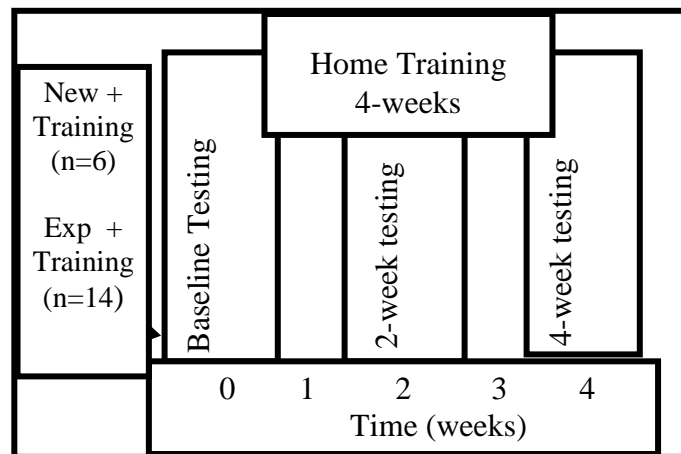
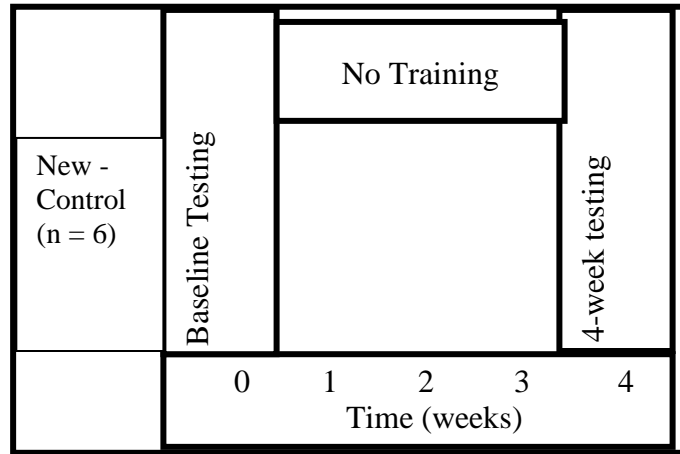


Figure 3.1 (continued)



### *Participants*

*Selection Criteria.* Thirty new and experienced HA users were initially recruited (see recruitment strategies below for additional detail) and enrolled in this experiment. Inclusion criteria were that subjects be between 50-80 years of age, presenting with mild to severe sensorineural hearing loss, and use of two HAs. Pure tone hearing levels could be no worse than 60 dB HL at 500 Hz and 90 dB HL at 2000 Hz for air conduction thresholds. All participants were native speakers of American English due to the fact that the training materials were in English. Additionally, vision or vision corrected acuity was adequate by self-report to see and operate a television screen and remote control. Finally, participants had daily access to a television and remote control through which they could receive the training.

*Exclusion criteria.* Persons with hearing levels that exceeded these criteria were excluded because the researchers thought that participants needed adequate residual hearing to be able to complete the training which was presented in an auditory only format. In addition, persons with a history of neurological or psychiatric disorder and or conductive hearing loss (defined as an air bone gap of > 15 dB) were also excluded.

### *Recruitment Strategies*

Participants were recruited through several methods. The recruitment flyer (Appendix A) was posted at several locations across the University of Kentucky campus and was also distributed at a local health fair. Twelve participants were recruited from



dispensing audiologists from either the University of Kentucky Medical Center or from private local hearing aid dispensing offices. An additional ten participants were recruited through personal contacts, word of mouth and through faculty members who were aware of the primary investigator's research study. Eight persons responded to direct advertisements about the study listed in the *University of Kentucky House Calls* (November 2009 issue), a community magazine and the local Senior Citizen's Center. The recruitment flyer was also shared with local neighborhood associations and was posted on Craig's list.

Each person who expressed interest in the research study was given a copy of the recruitment flyer. Potential participants then contacted the primary investigator and were screened by phone or by e-mail for possible eligibility. If eligible, candidates were invited to participate in the trial and were mailed a detailed description of the research project to review at their convenience.

#### *Group Assignment*

Thirty adult HA users were initially recruited and consented to participate (Appendix B) in this study according to the guidelines established by the University of Kentucky Internal Review Board. Four participants (three new HA users and one experienced HA user) were withdrawn from the study for individual or independent reasons. One person became ill, one person died, one encountered unexpected travel demands, and one simply chose to not finish the training. Therefore, the remaining 26 participants (15 males and 11 females) were assigned to one of three groups: 1) new HA users plus training, 2) experienced HA users plus training, and 3) new HA users – control group. New HA users used amplification for at least 4-weeks, but less than six months. Experienced HA users were defined as having worn their hearing aids at least two years by self report. New HA users were randomly assigned to the new + training (n=6) or the new - control (n=6) group as determined by random tables. Participants in the control group could be described as a delayed treatment group because they were provided with the training program at the conclusion of the study. For simplicity, this delayed treatment group was called the control group. Participants who had more than two years of HA use were assigned to the experienced plus training group (n=14). Both training groups began

training immediately after enrollment in the study. This design was chosen to control for possible acclimatization effects in new HA users.

### *Sample Size*

A power analysis was conducted to determine optimal sample size based on the primary measure called the Quick Speech in Noise (Quick SIN) (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004). Results from this test are reported in terms of decibel signal to noise ratio (dB SNR). If administering six lists sentences on the QuickSIN, a 1.6 dB SNR would be the critical difference necessary to verify change between conditions. Therefore, to detect a critical difference of 1.6 dB SNR between baseline and follow-up testing (with an estimated SD = 1.4 dB SNR), then for a *p value* <.05 with 80% power, 11 matched data sets across the 3 groups would be required. While estimates on attrition rates in clinical research can vary widely (Oka et al., 2000), the target recruiting number in this study was initially 36 participants (12 in each group) which included an additional person in each group to offset potential attrition. Despite extensive and varied recruitment efforts, this target enrollment was not obtained. Final enrollment for each group was as follows: new HA user + training (n=6), experienced HA user + training (n=14) and new HA user – control (n=6).

### *Demographics of Participants*

A summary of the demographic characteristics including age, education level, age hearing loss (HL) was identified, type of signal processing in HA and length of HA use is shown in Table 3.1. Education level was defined by highest year achieved with twelve years equal to high school graduation. Mean hearing levels, averaged across both ears are shown for each group in Figure 3.2.

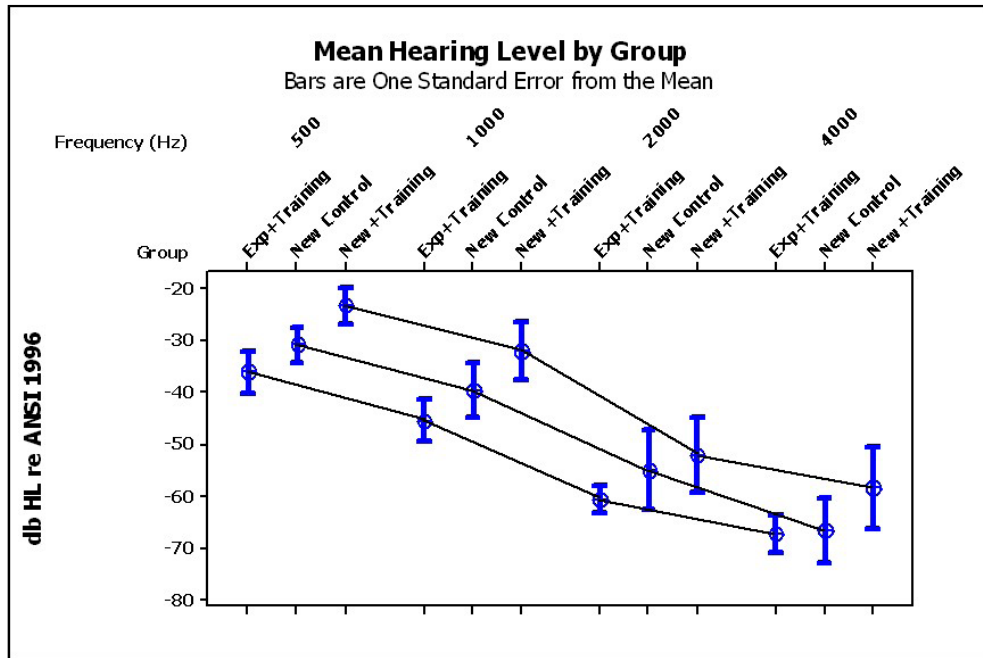
Table 3.1 Demographic characteristics of participants in study.

	Gender (M/F)	Age (year)	Education level (year)	Duration of HL (year)	Type of Processing	Length HA use
New + Training (n=6)						
1	F	67	22	0.5	Digital	1 mos.
2	F	64	16	26	Digital	3 mos.
3	M	76	22	0.5	Digital	6 mos.
4	M	55	18	10	Digital	2 mos.
5	F	52	18	20	Digital	3 mos.
6	M	76	22	20	Digital	1 mos.
Exp + Training(n=14)						
7	M	58	22	52	Digital	52 yrs.
8	F	69	12	17	Analog	18 yrs.
9	F	70	18	15	Digital	20 yrs.
10	F	79	22	4	Digital	2 yrs.
11	F	64	12	10	Digital	2 yrs.
12	M	67	16	22	Digital	12 yrs.
13	F	62	18	17	Digital	12 yrs.
14	M	61	22	11	Digital	5 yrs
15	F	75	16	4	Digital	4 yrs
16	M	75	16	15	Analog	9 yrs
17	F	60	18	26	Digital	25 yrs
18	M	68	18	10	Digital	10 yrs
19	F	78	18	13	Digital	13 yrs
20	M	74	18	13	Digital	2 yrs

Table 3.1(continued)

	Gender (M/F)	Age (year)	Education level (year)	Duration of HL (year)	Type of Processing	Length HA use
New - Control (n=6)						
21	M	68	12	18	Digital	2 mos.
22	M	65	16	14	Digital	6 mos.
23	F	54	16	4	Digital	2 mos.
24	M	76	16	30	Digital	3 mos.
25	M	64	22	3	Digital	2 mos.
26	M	71	22	50	Digital	1 mos.

Figure 3.2 Mean audiometric thresholds for the twenty six participants enrolled in the study.



## Dependent Measures

Several outcome measures were administered in this study. A brief description and rationale for each measure is provided below.

### *Quick Speech in Noise (Quick SIN)*

The Quick SIN (Killion et al., 2004) is a sentence based speech recognition test in noise. As such, it is an ecologically valid measurement since hearing in noise is one of the most common complaints of HA users. Test re-test reliability for the Quick SIN has been reported to be sensitive to detecting changes in speech recognition ability in noise by HA users (Mendel, 2007).

Procedures for the Quick SIN were as follows. Sentences were administered in the aided condition in soundfield with normal user HA settings. Listeners were positioned one meter from the speaker. This position was pre-measured and marked so that each participant sat in the same place for each visit. One practice list of six sentences was given to familiarize the participants with the task. Six homogeneous sentence sets were selected based on findings of McArdle and Wilson (2006). Presentation lists of sentences were counterbalanced across sessions and participants. Presentation level of sentences was fixed at 70 dB HL for all assessment sessions unless pure tone average hearing levels exceeded 45 dB HL. In this situation, presentation level was increased to the participant's desired sensation level according to the Quick SIN procedural manual using a loudness judgment chart (Appendix C). Listeners were instructed to select a level that was "loud, but OK" using the loudness judgment chart as a reference. The level of the multi-talker babble was varied at fixed SNRs that vary in 5 dB steps from +25 dB SNR to 0 dB SNR. Directions for this task were read from a script to participants before testing began. Participants were instructed that they would hear six sets of six sentences each spoken by a female voice with several other talkers in the background. Participants were instructed to repeat each sentence while ignoring the background babble. The background talkers became progressively louder, making it more difficult to understand the woman's voice. Participants were also encouraged to guess even if they were not sure. There were five keywords per sentence and participants earned one point for each keyword repeated

correctly. Testing was terminated if sentences at the +5dB SNR level were all incorrect (Wilson, McArdle, & Smith, 2007). The SNR loss score from six sentence sets was averaged together to obtain an SNR loss value. A reduction in SNR loss value suggests an improvement in ability to understand speech in noise.

### *Compressed Speech*

Compressed Speech (Department of Veterans Affairs, 1998) is a word recognition test that uses a 45% compression rate leaving 55% of the original speech signal so that pitch, prosody and reverberation characteristics of the spoken words remain unchanged. Given that many HA users report difficulty understanding rapid speech (Kochkin, 2002) this test was deemed ecologically valid even though its psychometric properties are unknown.

A 50-item word list was presented at the same level for all assessments (70 dB HL) in soundfield, with listeners positioned one meter from the speaker. If hearing levels exceeded 45 dB HL, words were presented at desired sensation level using a loudness judgment chart as described earlier. All words were presented within the context of a carrier phrase “Say the word\_\_\_\_\_”. Participants were instructed to repeat the final word. Scores were calculated in terms of percent correct. Ten practice items were given before initiating the test.

### *The Synthetic Sentence Identification (SSI)*

The SSI (Speaks & Jerger, 1965) is a competing speaker task where both the target and competing signal are presented simultaneously. Additionally, both signals have meaningful content. During the SSI, listeners heard a nonsense sentence and an ongoing narrative about the life of Davy Crockett presented simultaneously. As such it could be considered an informational masking task (Schneider, Li, & Daneman, 2007). Test re-test reliability with this measure has been demonstrated in older adults (Dubno & Dirks, 1983). In addition, the SSI has been used to differentiate benefit between types of amplification (Jerger & Hayes, 1976) and between individuals with different types of brainstem lesions (Jerger & Jerger, 1975).

Participants were given an answer sheet with each of the ten synthetic sentences on it (e.g. “Small boat with a picture has become” or “Go change your car color is red”).

The presentation level of the synthetic sentence remained fixed at 70 dB HL unless hearing levels exceeded 45 dB HL, or if target deviations for the Verifit exceeded 10 dB. In either of these conditions, sentences were presented at desired sensation level as described earlier. After listening to the competing speech signals, participants were asked to identify the number of the sentence that they heard. Initially, the synthetic sentences were easy to hear because the level of the message was louder than the level of the narrative. The relationship between the level of the message and the level of the narrative is called the Message to Competition Ratio (MCR). Reliability of the SSI improves when participants are given adequate practice lists (Dubno & Dirks, 1983). Therefore, participants completed three practice lists, at varying MCRs so that they could adapt to the listening task. The first practice list was presented at a +10 dB MCR level so that the message was 10 decibels louder than the competition. The second practice list was presented at a 0 dB MCR and the final practice list at -10 MCR. For assessment, participants completed three test lists which were all administered at -10 dB MCR. Each list was comprised of ten sentences. An average percent correct score was calculated from the three test lists.

### *Speech, Spatial and Qualities (SSQ)*

The SSQ (Gatehouse & Noble, 2004) is a self-assessment measure designed to reflect dynamic real world listening conditions encountered by most listeners. This 50-item questionnaire covers three subscales and includes questions related to a) hearing speech, b) spatial hearing (i.e. localization) and c) other qualities of hearing. The SSQ has been used to describe differences in hearing abilities in daily life between unilateral and bilateral cochlear implant users (Noble, Tyler, Dunn, & Bhullar, 2008) and between monaural and binaural HA users (Noble & Gatehouse, 2006). This test was selected because items address specific communication function activities that listeners encounter routinely such as listening in noise and understanding multiple talkers at one time.

For purposes of this investigation, questions from the “hearing speech” and “qualities of hearing” subscales were considered relevant. Responses were scored on a 0-10 visual analog scale where 0 indicated great difficulty and 10 indicated no difficulty. All participants completed this questionnaire independently which has been shown to be

consistent with an administrator application format (Noble et al., 2008). One could argue that after training, individuals may perceive less difficulty in such listening conditions. For instance, several questions target how well listeners are able to understand when they have to focus on one speaker while ignoring another speaker. Of particular relevance are several questions related to perceived effort of listening, such as how easily they can understand sounds when trying to listen to someone else.

#### *International Outcomes Inventory- Hearing Aid (IOI-HA)*

The IOI-HA (Cox & Alexander, 2002) is a brief, 7-item questionnaire (Appendix D). Each item addresses a different domain: HA Use, Benefit, Residual Activity Limitations, Satisfaction, Residual Participation Limitations, Impact on Others and Quality of life (Cox, Alexander, & Beyer, 2003). Internal consistency is good and test-retest reliability is high in both private pay (Cox & Alexander, 2002) and veteran populations (Smith, Noe, & Alexander, 2009).

The IOI was selected to administer to the control group participants to evaluate the global effectiveness of HA fitting. Responses were scored from 1 to 5 with higher scores suggesting better outcomes. (Cox & Alexander, 2002). The IOI- HA was administered to individuals in the control group only at the 4-week follow-up session.

#### *International Outcomes Inventory –Alternative Intervention (IOI-AI)*

The IOI-AI (Noble, 2002) is a brief, 7-item questionnaire (Appendix D) that was revised from the IOI-HA described above. Noble (2002) proposed that the IOI-HA could be modified so comparisons could be made to evaluate the effectiveness of non HA based interventions such as training, surgery or counseling. Researchers have used this alternative form to assess the effects of a communication program for older adults with hearing loss (Kramer, Alessie, Dondorp, Zekveld, & Kapteyn, 2005; Hickson, Worrall, & Scarinci, 2006). In both these studies, the IOI-AI was shown to be responsive to the intervention after treatment and in post-treatment follow-up sessions.

As in the IOI-HA, responses on the IOI-AI are scored from one to five, with higher scores suggesting better outcomes. Two brief questions were added to the IOI-AI to ascertain overall compliance. These two questions were “Did you complete all of the training sessions?” and “How long did it take you to complete the training program?”.



The IOI- AI was administered to individuals in the treatment groups only at the 4-week follow-up session.

### *Reading Span Test (RSPAN)*

The Reading Span Test (RSPAN) (Conway et al., 2005) is a visual, dual-task assessment that reflects working memory. The purpose of the task is to determine how many letters persons can recall while also reading sentences. Test-retest reliability of the automated RSPAN is considered good in a young adult population ( $r=.627-.76$ ) (Unsworth, Heitz, Schrock, & Engle, 2005). Researchers have concluded that RSPAN taps working memory capacity because construct validity has been demonstrated across a number of other working memory measures (i.e., Raven progressive matrices, operation span tasks) (Unsworth, Redick, Heitz, Broadway, & Engle, 2009).

While a wide variety of span measures exist, no single cognitive measure is completely correlated with speech perception ability. The automated version of the RSPAN was chosen because tests of sequential working memory appear to have the strongest correlation with sentence recognition in noise (Lunner, 2003; Rudner, Foo, Ronnberg, & Lunner, 2007; Ronnberg, Rudner, Foo, & Lunner, 2008). This measure was important to include because it was used to examine the relationship between cognition and benefit from training.

In the present study, participants completed an automated version of the RSPAN via a standard desktop computer screen (Conway et al., 2005). Participants were familiarized with each task involved in this test. First, participants practiced recalling a series of letters which appeared on the screen one at a time. The letters were presented in sets ranging from three to seven letters. Participants demonstrated recall by entering their responses on a computer screen with a mouse click. The researcher emphasized that perfect recall was not be expected. Second, participants demonstrated reading comprehension by reading sentences on the computer screen and judging if they were true or false. They entered a true or false response after reading each sentence accordingly. The third task combined the first and second tasks, so that participants read a sentence, decided if it was true or false, and then saw individual letters on the screen in between sentences. Sentences and letters were presented in varying set sizes which

ranged from three to seven. For example, if the set size was five, then the participant had to read a sentence, judge if each was true or false and view a letter. This sequence for a set size of five occurred five times. After all five sentences and five letters had been presented, participants were asked to recall the five letters that they had seen. Letters were selected from a template of 12, pre-selected letters. Four practice items from each of the three types of tasks were provided before the test began. Three sets of each set size of sentences and letters were presented and took approximately 20 minutes to administer. Working memory was measured by the total number of target letters recalled. The RSPAN is scored from 0-75, with a higher score indicating larger working memory span.

## Procedures

### *Assessment Procedures*

Assessments were completed in two different settings. HA Verification (Verifit) was completed in the Audiology Department of the Kentucky Clinic located in the University of Kentucky Medical Center. All other assessments were completed in the Communication Disorders Clinic located in the College of Health Sciences at the University of Kentucky. A complete list of assessments conducted during this study is located in Appendix E.

*HA Verification.* To verify audibility of speech with amplification, an objective measurement using Audioscan's HA Verification System® (Verifit) was performed using a speech mapping method. The purpose for this measure was to verify that amplified speech was audible for participants before each assessment condition (baseline, 2-week and 4-week). In this assessment, a simulated speech signal was used to create an ideal target of the amplified speech region within the participant's residual auditory area. Participants were positioned 24-inches from and directly in front of the speaker. The probe tube and the HA were positioned and calibrated according to procedures outlined in the user manual. National Acoustics Laboratories–Non Linear (NAL-NL1) prescriptive fitting targets as described by Dillon (1999) were used to quantify audibility of speech presented at average intensity levels. Given that participants received HAs from a wide number of dispensers, HAs could not be re-programmed before proceeding with other assessments. Therefore, if prescribed targets deviated by more than 10 dB SPL at 500,

1000 and 2000 Hz, the investigator increased or decreased presentation level for speech measures accordingly.

While overall speech mapping measures made with Verifit were expected to deviate from target (Swan & Gatehouse, 1995) deviations across evaluation sessions were not expected. If values deviated more than 10 dB from the target, then presentation levels were adjusted during listening tasks. This was done to insure consistent audibility across sessions. HA verification was performed at each visit to be certain that HA settings were not significantly different between assessments. Participants in the training groups underwent Verifit testing at baseline, 2-weeks and 4-weeks. Participants in the control group completed Verifit testing at baseline and 4-weeks, because they were not seen at the 2-week interval.

*Behavioral Listening Procedures.* All behavioral listening tests described previously (Quick SIN, SSI and Compressed Speech) were conducted in a double walled acoustically treated chamber (Industrialized Acoustics Corporation) adjacent to a single wall control room. A Madsen Orbiter 922 clinical audiometer calibrated to meet current specifications (ANSI, 1996) was used for threshold and speech recognition testing. Speech recognition tests were presented via a Sony Compact Disk player (CDP CD-375) through the audiometer and delivered through the soundfield speakers. Stimuli were presented at 0 degree azimuth, with both speech and noise coming from the same speaker. Distance between the listener and speaker was fixed at 1 meter.

Each participant completed a background questionnaire (Appendix F). A pure tone air and bone conduction hearing test was conducted to confirm hearing thresholds. Next, participants in the training groups completed behavioral listening tests. All behavioral tests were presented in a counterbalanced order across testing sessions and participants. Instructions for each measure were presented via pre-written scripts so that each participant received the same instructions. These measures included: 1) Quick Speech in Noise (Quick SIN) (Killion et al., 2004); 2) Compressed Speech (Department of Veterans Affairs, 1998); and 3) Synthetic Sentences Identification (SSI) (Speaks & Jerger, 1965). Next, participants' perception of communication function both before and after training was assessed with the Speech Spatial and Qualities of Hearing Questionnaire (SSQ) (Gatehouse & Noble, 2004) as described earlier. Perceptions about

benefit and satisfaction with the training were also measured after training with the International Outcome Inventory for Alternative Interventions (IOI -AI ) (Noble, 2002). Finally, participants completed an automated version of the Reading Span test (Conway et al., 2005). Together these behavioral and self-assessment tests took approximately 120 minutes to administer during baseline testing. Participants were given short breaks as needed during the assessment procedures. Participants in the training group completed behavioral listening measures at baseline, 2-weeks, and 4-weeks. Persons in the control group completed behavioral listening measures at baseline and 4-weeks. The decision to evaluate the control group at baseline and at 4-weeks was based on the assumption that it was not necessary to monitor performance since they were not receiving the training. Additionally, there were practical aspects related to scheduling that contributed to the decision to evaluate the control group only twice rather than three times, as was conducted on the training groups.

#### *Treatment Phase Procedures*

After completing the initial baseline activities, participants in the training groups received an orientation about using the home DVD auditory training program. Individual instruction on use of the DVD was demonstrated along with step by step written instructions (Appendix G). General instructions about how to set up the home training environment were reviewed (Appendix H). Participants were also instructed on how to use the daily score sheet as shown in Appendix I. This score sheet served two functions. First each participant recorded daily scores that were provided at the end of the training session for each condition (speech in noise, rapid speech, and competing speaker). Participants then entered these scores before their next training session. Second, this score sheet provided documentation that the participants completed the training. Data on this score sheet were not analyzed.

Each participant in the treatment groups was given a copy of LACE™ DVD for training at home. In the event that a participant did not have a DVD player, or had one, but was unable to set it up, a portable DVD player was loaned for use during the training portion of this study. Of the twenty six participants, three borrowed a portable DVD player. Participants completed a total of 4-weeks of home DVD auditory training

program. After completing ten lessons, participants returned for a 2-week follow-up appointment where behavioral listening tests were completed. After this, both training groups were instructed to repeat the same ten training lessons as they did during the first 2-week training period. In the DVD version of LACE, there are not alternative topics to select from, so participants were training on the exact same stimuli during the second 2-weeks as they did the first 2-weeks. When the second set of lessons was completed, participants returned again for a final 4-week follow-up. The complete schedule of assessment and training schedule for both groups is shown in Appendix E.

### *Contact with Participants*

The researcher made three contacts with the persons in the training groups before and during this study. The first contact occurred on the day before training began. Participants were either called or e-mailed to remind them to begin training and to inquire about set up problems. The second contact occurred after the end of the week two of training to remind participants about the follow-up appointment. The third contact occurred after the end of the fourth week to remind them about their final follow-up appointment. The researcher made one contact with the participants in the control group during this study to remind them about the 4-week follow-up appointment.

### *Compensation*

Parking fees were paid for participants in this study. In addition, participants in both the trained and control groups were compensated \$50.00 at the conclusion of the study. Funding for this was secured through internal department funds in the College of Health Sciences. The LACE™ DVDs were donated by Neurotone, the company that developed and currently distributes LACE training program materials. Participants in the training groups were allowed to keep the training DVD at no expense at the conclusion of the study. Participants in the control group were given the training DVD at no expense at the conclusion of the study.

## Reliability

### *Procedural Reliability*

To ensure that participants in the training groups were instructed in a similar manner about how to use the DVD training program, procedural reliability was measured in 20% (n=8) of the participants during explanation of the training program. A review sheet was given to each participant including how to operate the DVD (Appendix G) as well as room set-up procedures for home training. A graduate student in speech language pathology, trained on the research protocol, completed a check sheet (Appendix J) verifying that researcher reviewed each step with the participant. This verification was completed during the DVD orientation with the graduate student, researcher and participant all present. Selection for procedural reliability was considered random because it was based on the graduate student's availability. The number of response items that the researcher reviewed compared to the total number of potential items to be reviewed was calculated. Procedural reliability was measured as 99%.

### *Inter-scorer Reliability*

To ensure accuracy in scoring the talk back responses from research participants, inter-scorer reliability was measured during the Quick SIN and Compressed Word tests for 20% (n=8) of the participants. The primary investigator and a graduate student in speech language pathology, who was trained in administration of these test procedures, simultaneously but independently, scored talk back responses during administration of these tests (Appendix K). Selection for inter-scorer reliability was considered random because it was based on the graduate student's availability. Inter-scorer reliability was calculated using the following formula:  $[\frac{\text{the total number of agreements}}{\text{the total number of possible agreements}}] \times 100$ . Inter-scorer reliability was measured as 95% for the Compressed Words test and 96% for the Quick SIN test.

## Data analysis

Results were collected in an Excel database and imported into Statistical Package for the Social Sciences (SPSS). All statistical analyses were performed using SPSS v11.5 or higher. Descriptive statistics (n, mean, standard deviation, standard error) were

calculated for continuous variables (i.e. Quick SIN, Compressed Speech), while counts and percentages were provided for categorical variables (i.e. number of experienced vs new HA users, gender). A  $p < .05$  was considered statistically significant for all statistical tests. Statistical analysis was completed for participants who completed at least half of the training sessions as reflected in a self report questionnaire.

Although random assignment was used for the new HA user groups, no random assignment was used with the experienced HA user group. Therefore, groups were compositionally different on certain characteristics (see description in Demographics for additional information). Differences between new and experienced users were quantified for continuous and categorical variables. Comparisons between groups were made with analysis of variance (ANOVA) to test for independence for continuous and categorical variables respectively.

To answer question one, an analysis was computed to measure the effect of training on listening abilities by comparing treatment differences based on the Quick SIN, Compressed Speech and the SSI for each group at baseline and 4-weeks. A general linear model, repeated measures (ANOVA) was used where the “groups” of interest (between subjects’ factor) were: new users + training, experienced users + training and new users – control. In addition, the different assessment conditions of interest (the within subjects’ factor) were “time” at Baseline and 4-week. Post-hoc tests were made to compare which groups demonstrated the greatest differences.

To further evaluate the rehabilitative effects of the LACE training program, effect sizes (ES) (Cohen, 1992) were calculated for each behavioral listening measure (Quick SIN, Compressed Speech and SSI) both between and within groups using the formula below. Effect sizes were interpreted according to conventional guidelines (Cohen, 1992) of “small” ( $d = .2$ ), “moderate” ( $d = .5$ ) or “large” ( $d = .8$ ).

$$\text{Between group ES} = \frac{\text{Mean difference (training)} - \text{Mean difference (control)}}{\text{Standard Deviation (control)}}$$

$$\text{Within group ES} = \frac{\text{Mean score (4-weeks)} - \text{Mean score (baseline)}}{\text{Standard Deviation (baseline)}}$$

For between groups ES testing, an unpooled standard deviation (SD) from the control group at 4-weeks was applied to avoid overestimating the ES (Wilson, Becker, & Tinker, 1995). For within groups ES testing, the standard deviation obtained at baseline for the group of interest was used to compute the ES. This accounted for the correlation that exists between baseline and 4-week measures in a repeated measures design. If a pooled standard deviation were used, the ES could be overestimated (Dunlop, Cortina, Vaslow, & Burke, 1996).

To answer the second question in relation to how treatment differences change over time (baseline, 2-weeks and 4-weeks) for new users + training, experienced users + training, a two-way repeated measures ANOVA analysis was used. New users in the control group were not included in this analysis because assessments were only performed at baseline and 4-weeks. In this analysis, the outcome of interest is the Quick SIN score for sentence recognition ability at each time point rather than just the difference between pre- and post-tests. Therefore, this analysis was used to compare the means over time and investigate interactions of group and time. Within group and between group ES were calculated for the Quick SIN scores to further evaluate training effects over time.

To answer the third question about change in communication function after training, the means and standard deviations were calculated for the Hearing Speech and Qualities of Hearing subscales on the SSQ. Next, a one-way ANOVA was completed to assess if there were significant differences between groups at baseline. Next a repeated measure ANOVA was completed to determine if there were any differences between baseline and follow-up. Post-hoc tests were calculated to determine if there were treatment differences in mean perception of hearing ability between groups. Within group and between group ES were calculated for the SSQ to further evaluate training effects.

The fourth question regarding perceived benefit from training was analyzed using responses from the IOI-AI. Descriptive statistics (mean, standard deviation) were calculated for each of the seven questions including perceived activity limitations, participation restrictions and quality of life. A one-way ANOVA was used to compare the



results between new and experienced users in the trained groups before and after training. A Least Squares Difference (LSD) method was used to compare treatment group means after the null hypothesis was rejected. Descriptive statistics were calculated for the responses on the IOI-HA completed by the new users in the control group. However, questions on the IOI-HA are slightly different than the IOI-AI. Therefore, hypothesis testing between the two measures could not be conducted.

The fifth question about the relationship between working memory and benefit from training was answered by first conducting a correlational analysis to investigate which factors may have influenced outcome with training. Pearson correlation coefficients were calculated to measure the relationship between the benefit from treatment and possible explanatory variables including; baseline measures and demographic variables. After examining the correlational analysis, a stepwise regression analysis was conducted to determine which factors contribute the most in explaining the variance of the dependent variable related to listening in noise.

## Chapter Four – Results

The areas addressed in this chapter are the results about participant demographics including HA verification and cognitive function. These demographics are followed by the results for each research question as discussed in chapter one.

### Participant Demographics

Twenty-six participants (15 males and 11 females) completed this study. Three groups were formed: new + training (n=6), experienced + training (n=14) and new – control (n=6). Table 4.1 displays the means, standard deviations (SD) and counts for characteristics including age, gender, duration of HL, duration of HA use, and degree of HL (based on 4- frequency pure tone average for the better ear).

Comparisons between the experienced and new HA users groups show that there were some differences between groups. As expected, results from a one way ANOVA showed that there was a significant difference ( $F(2,24) = 4.991, p = .016$ ) between groups for length of HA use. Mean length of HA use for new HA users was 3 months in both the training and control group, whereas mean length of HA use for experienced HA users was 12.8 years. Mean pure tone hearing levels for the better ear were averaged at 500, 1000, 2000 and 4000. One way ANOVA testing showed that there was a significant difference in the degree of hearing loss between groups ( $F(2,24) = 3.481, p = .048$ ). Post hoc measures indicated that the mean hearing loss of participants in the experienced HA user group (48.5 dB HL) was significantly different ( $p = .019$ ) from the mean hearing loss of participants in the trained new HA user group (32.7 dB HL). Although the mean hearing loss of new users in the control group was slightly worse (39.7 dB HL), this was not significantly different from the mean loss of persons in either of the training groups. While there was variability in duration of hearing loss between groups, this difference was not significant since all groups presented with large ranges of duration of loss as shown in Table 4.1. All participants reported adult onset of hearing loss except for one person in the experienced HA user group who reported that he first experienced hearing loss during childhood. Although the mean age varied slightly between groups, no significant difference between groups was observed. Pure tone hearing levels were

monitored, and did not change more than 5 dB between baseline and follow up testing after 4-weeks of training.

Table 4.1 Demographic means, counts and ranges for participants in each group. Ranges are reported in parentheses.

	<b>New + Training</b>	<b>Exp + Training</b>	<b>New –Control</b>
Number	6	14	6
Gender (male/female)	2/4	6/8	5/1
Age – years	61(52-77)	68 (58-79)	64(54-76)
Hearing Loss (dBHL better ear )*	32.7 (20-51.3)	48.5 (31.3-67.5)	39.7 (22.5-55.0)
Duration of HL (years)	10.1(.5-26)	16.35 (4-52)	17.1(3-50)
Length of HA use (years)**	.25(.08-.5)	12.8 (2-52)	.25(.16-.41)
Education (years)	18.1(16-22)	17.8(12-22)	15.3(12-22)
12= High School			

\* Significant difference ( $F(2,23)=3.5, p=.048$ ) for degree of hearing loss between New + training vs Exp + training, but not between Exp+ training vs New – Control

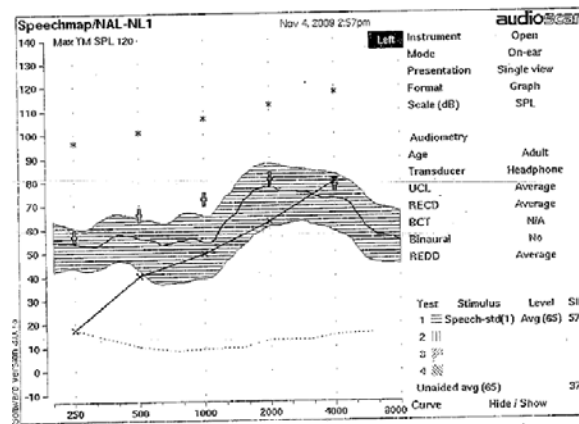
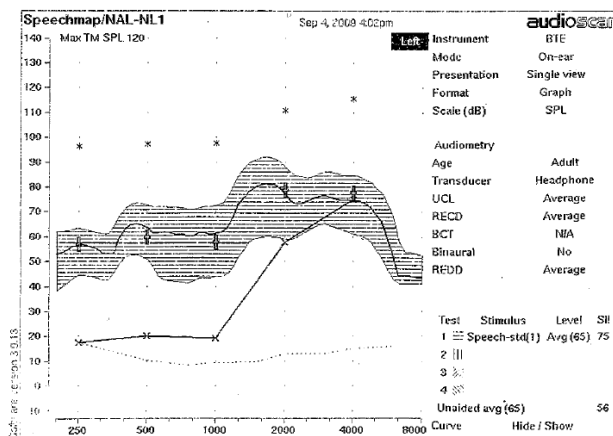
\*\* Significant difference ( $F(2,23) = 3.481, p = .019$ ) for length of HA use between New + training vs Exp + training and between New – Control vs Exp + training.

### *Verifit Measure*

Average deviation from target values for Verifit measures were calculated for participants in the training groups for both ears at the baseline, 2-weeks and 4-week assessment sessions. Average deviation from target values was calculated for both ears at baseline and 4-weeks for the control group. Values were calculated using the average deviation across sessions for frequencies 500, 1000, and 2000 Hz. Deviations at 4000 Hz were not calculated because at least half of the 26 participants showed deviation values

that exceeded 10 dB SPL from the prescribed target. An example of a Verifit response that met the prescribed target, as well as a Verifit that did not meet the prescribed target is shown in Figure 4.1

Figure 4.1 Examples of HA verification. Upper figure shows that amplified speech is audible because the Verifit response meets prescribed targets. Lower figure shows that amplified speech is not completely audible because the Verifit response does not meet prescribed targets.



A repeated measures ANOVA showed that there was not a significant difference ( $F(1,2) = .389, p=.539$ ) between groups in average deviation from target for the right ear between baseline and 4-weeks. There was also no significant difference ( $F(1,22) = .056, p=.815$ ) between groups in average deviations from target for the left ear between

baseline and 4-weeks. Finally, ANOVA testing indicated that there was no significant difference between the New + training and the Experienced + training for either ear at baseline, 2-weeks or 4-weeks ( $F(1,17) = .001, p = .979$ ). The mean deviations in dB SPL from prescriptive target values across groups are reported in Table 4.2.

Table 4.2 Mean deviation values obtained with Verifit. Values represent the average dB SPL deviation from prescriptive target values (NAL-NL) for right (R) and left (L) ears at 500, 1000 and 2000 Hz for treatment and control groups at each session.

	<b>New + Training</b>	<b>Exp. + Training</b>	<b>New – Control</b>
Baseline	R: -8.58(1.5)	R: - 6.7( 5.5)	R: - 9.1 (3.7)
	L: -7.4(2.8)	L: -7.8(6.0)	L: -8.9(3.7)
2-weeks	R: -7.0 (3.2)	R: -6.6(5.5)	DNT
	L: -7.0(3.3)	L:- 8.2 (7.0)	DNT
4-weeks	R: -6.5(3.0)	R: -6.7( 5.2)	R: -8.6 (5.46)
	L: -7.07(4.7)	L:8.2(7.4)	L: 9.2(2.3)

*DNT = Did not test control group after 2-weeks of training.*

### *Cognitive Measure*

The specific cognitive process evaluated in this study was working memory as indicated by the results on the Reading Span Test (RSPAN). The total number of letters recalled is reported with the highest possible raw score being seventy-five (75). One participant in the experienced HA user group was unable to complete this task due to inability to operate the mouse and enter responses in a timely manner. Interestingly, this same individual required assistance from her spouse to complete the LACE training when manipulating the remote control. Data from the remaining 25 participants are reported in Table 4.3. A one-way ANOVA demonstrated that there were no significant differences in working memory between groups based on the RSPAN ( $F(2,24) = .068, p = .0934$ ).

Table 4.3 Means (SD) for working memory span scores base on RSPAN for each group.

<i>RSPAN</i> <i>score</i>	<i>New +</i> <i>Training</i> <i>(n=6)</i>	<i>Exp +</i> <i>Training</i> <i>(n=13)</i>	<i>New -</i> <i>Control</i> <i>(n=6)</i>
M	44.0	41	43.2
SD	16.03	19.25	16.16
% correct	58%	55%	58%

### Questions

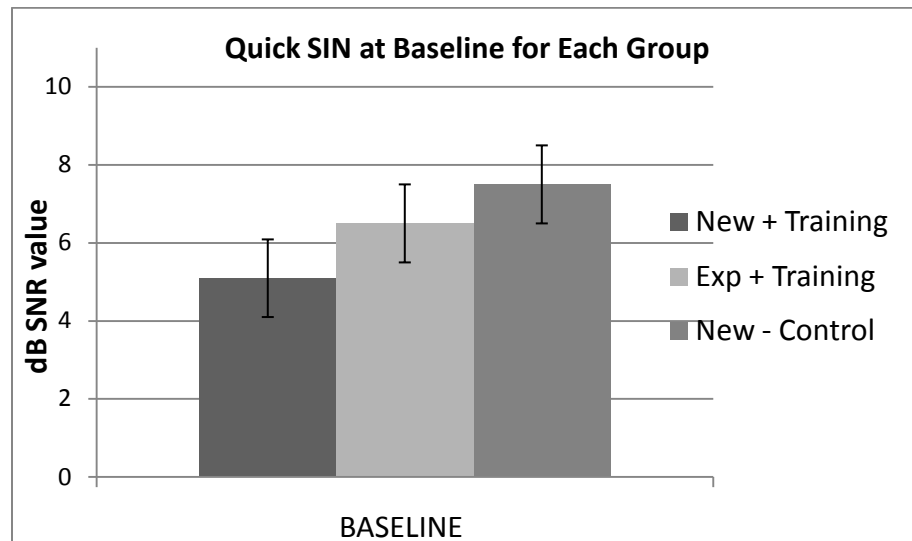
This first question investigated whether or not the use of the LACE™ home based auditory training program in the DVD format resulted in improved behavioral listening abilities for new and experienced adults HA users. Since there were three different types of behavioral listening skills trained with the LACE program, three different outcome measures were used to assess benefit: sentence recognition in noise; rapid speech; and competing speaker. The results for each outcome measure are discussed separately.

#### *Question 1a*

Does the use of a home auditory training program in a DVD format for 4-weeks result in improved speech understanding in noise for new and experienced adult HA users alike who receive the training compared to a control group of new HA users who do not receive the training?

Results from the Quick SIN test are shown in Table 4.4. The mean dB SNR for 50 % recognition of words in sentences observed at baseline was 5.1 dB for new HA users in the trained group, 6.5 dB for the experienced users in the trained group and 7.5 dB for the new users in the control group. While no significant differences in dB SNR values were observed between the groups at baseline ( $F(2,25) = 8.95, p = .422$ ), some variability between groups was observed as shown in Figure 4.2

Figure 4.2 Mean baseline dB SNR from QuickSIN for each group. Higher scores represent greater difficulty understanding speech in noise. Error bars represent 1 standard deviation.



Results after training are presented in Table 4.4. After training, the largest mean improvement in dB SNR after 4-weeks of training was 2.6 dB for the new users + training. Improvements in dB SNR of 1.6 dB and 1.8 dB were obtained for experienced users + training and new users – control, respectively. A one-way repeated measures ANOVA showed that there was a significant main effect of time between baseline and 4-weeks after training  $F(1,23) = 31.9, p=.001$ , but there was not a significant main effect of group between baseline and 4-weeks after training. Almost all (5/6) of the new + training participants improved their dB SNR by more than 1.6 dB (95% CI for critical differences), while the majority (8/14) of the participants in the experienced +training group improved their dB SNR by more than 1.6 dB. Two participants from the experienced HA users group declined following training. Mean changes in SNR are illustrated in Figure 4.3.

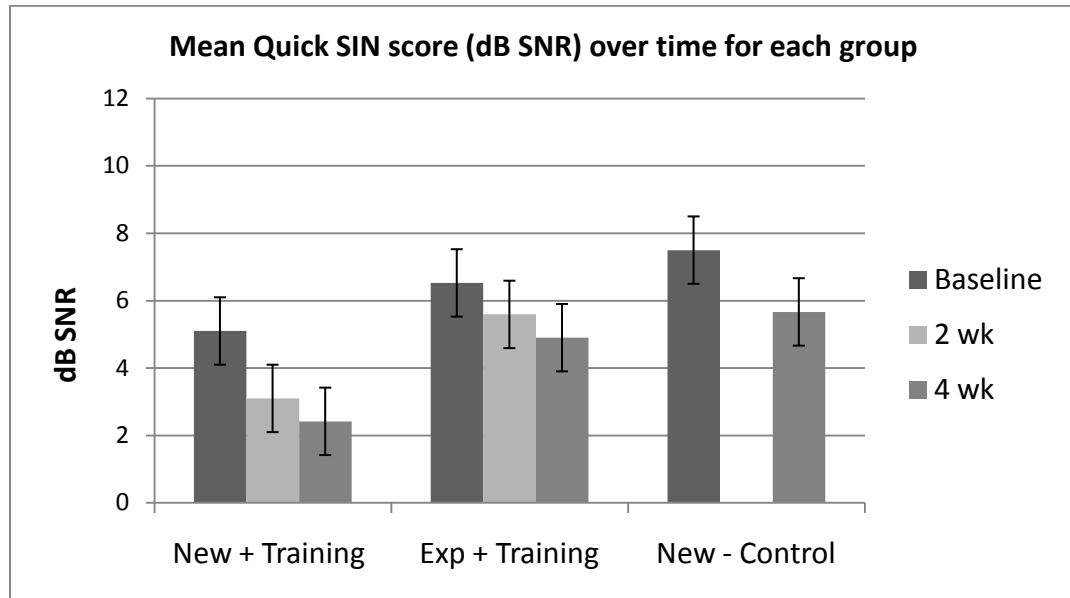
Table 4.4 Mean scores for Quick SIN (dB SNR) with (SD) at baseline, after 2-weeks, and after 4-weeks of training, change scores and within group effect sizes for training and control groups. Change scores and effect sizes were calculated from performance at base to 2-weeks and baseline to 4-weeks with 95% confidence interval (CI). Lower scores represent better ability to understand speech in noise.

	<b>New +</b>		<b>Exp +</b>		<b>New -</b>	
	<b>Training</b>		<b>Training</b>		<b>Control</b>	
	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>
Baseline	5.1	2.4	6.5	3.3	7.5	3.4
2-wks	3.1	1.8	5.6	3.2	DNT	DNT
4-wks	2.4	2.1	4.9	3.4	5.7	2.9
<u>Change</u>						
Base- 2-wks	2.0	.49	.9	.51	DNT	DNT
Base- 4-wks	2.6	1.5	1.6	1.8	1.8	1.6
<u>Within Group</u>						
<u>Effect Size</u>		<b>95% CI</b>		<b>95% CI</b>		<b>95% CI</b>
Base -2-wks	.83	(1.92)	.27	(1.72)	DNT	DNT
Base -4-wks	1.08	(1.92)	.48	(1.72)	.52	(2.7)

*Wks = weeks, DNT = Did not test control group at 2-week interval.*



Figure 4.3 Mean scores for Quick SIN (dB SNR) at baseline, 2-weeks and 4-weeks for both training groups and the control group. Error bars represent 1 standard deviation. Lower scores represent better ability to understand speech in noise.



*Effect Size.* Within group effect size calculations and 95% CI for the Quick SIN are shown in Table 4.4. Observed within group effect sizes were moderate in the control group ( $d = -.52$ ), and in the experienced + training group ( $d = .48$ ), but large in the new + training group (1.08) (Cohen, 1992). Confidence intervals illustrate the degree of variability within groups on this test.

Between group effect sizes were calculated, as previously described, to further analyze differences between the New HA users in the trained and control group. Between group effect sizes with 95% confidence intervals for the Quick SIN are shown in Table 4.5 and were considered moderate ( $d = .5$ ). Confidence intervals illustrate the degree of variability.

Table 4.5 Between Group ES (New + training and New- control) for each outcome measure. Upper and lower bounds represent the 95% Confidence Interval.

Outcome measure	Confidence Interval for ES		ES (based on control group SD)
	lower	upper	
Quick SIN (dB SNR)	-0.48	1.48	.5 (moderate)
Compressed speech (% correct)	-6.93	7.15	-0.11 (small)
SSI (% correct)	-12.39	14.49	1.05 (large)
SSQ-Qualities	.14	1.51	.83 (moderate)
SSQ-Hearing Speech	-.39	2.65	1.52 (large)

*Question 1b*

Does the use of a home auditory training program in a DVD format (for 4-weeks) result in improved understanding of rapid speech for new and experienced adult HA users alike who receive the training compared to a control group of new HA users who do not receive the training?

The mean Compressed Speech (rapid speech task) scores are shown in Table 4.6 Scores are reported in terms of percent correct. The baseline score was 65% for new HA users + training, 60.6% for experienced + training and 53% for new users in the control group. A one way ANOVA showed that there were no significant differences between groups at baseline ( $F(2, 23) = .406, p = .67$ ).

The mean change score for compressed speech after 4-weeks of training was 5.7% for new HA users + training, 5.4% for experienced HA users + training and 6.7% for new HA users in the control group. These results are plotted in Figure 4.4. A one-way repeated ANOVA showed that there was a significant difference in compressed speech scores between baseline and 4-weeks after training ( $F(1,23) = 11.58, p = .002$ ), but again, there were no observed main effect for group.

*Effect Size.* Within group effect size calculations and 95% CI for the Compressed Speech test are shown in Table 4.6. Observed within group effect sizes were small in the control group ( $d = .22$ ), and small ( $d = .24$ ) in the experienced training group and small in the new + training group ( $d = .31$ ) (Cohen, 1992). Confidence intervals illustrate the degree of variability within groups on this test.

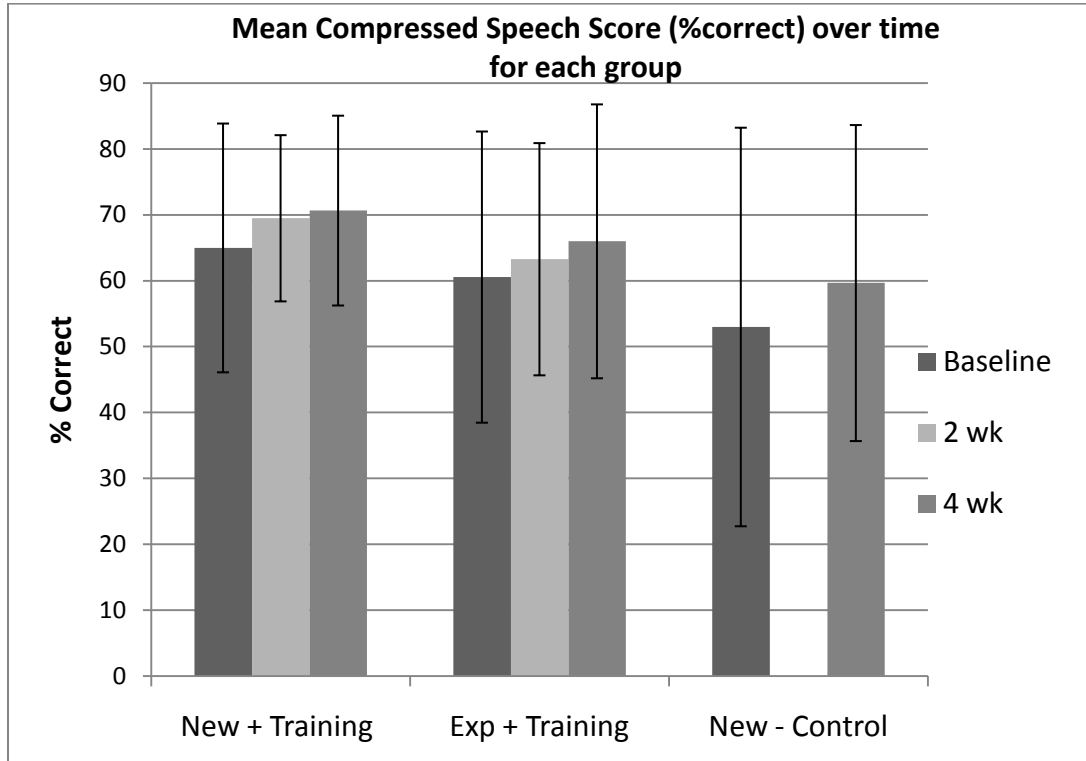
Between group effect sizes were calculated, as previously described, to further analyze differences between the New HA users in the trained and control group. Between group effect sizes with 95% confidence intervals for the Compressed Speech are shown in Table 4.5 and were considered small ( $-0.11$ ). Confidence intervals illustrate the degree of variability.

Table 4.6 Mean scores for Compressed Speech (% correct) with (SD) at baseline, 2-weeks and 4-weeks of training. Change scores and within group effect sizes (from baseline to 2-weeks and baseline to 4-weeks) with 95% CI for each group.

	<b>New + Training</b>		<b>Exp + Training</b>		<b>New – Control</b>	
	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>
Baseline	65.0	18.1	60.6	22.1	53.0	30.2
2-wks	69.5	12.61	63.29	17.6	DNT	DNT
4-wks	70.7	14.2	66.0	20.8	59.7	23.9
<u>Change</u>						
Base-4wks	5.7	5.2	5.4	8.8	6.7	8.8
<u>Within Group</u>	<b>95% CI</b>		95% CI		<b>95% CI</b>	
<u>Effect Size</u>						
Base -2-wks	.25	(14.4)	.12	(11.5)	DNT	DNT
Base-4-wks	.31	(14.4)	.24	(11.5)	.22	(24.1)

*Wks = weeks, DNT = Did not test control group at 2-week interval.*

Figure 4.4 Mean scores for Compressed Speech at baseline, after 2-weeks, and after 4-weeks of training for each group. Error bars represent 1 standard deviation. Higher scores represent better ability to understand rapid speech.



*Question 1c*

Does the use of a home auditory training program in a DVD format (for 4-weeks) result in improved understanding of competing speech for new and experienced adult HA users alike who receive the training compared to a control group of new HA users who do not receive the training?

The mean scores for the SSI (competing speaker task) are shown in Table 4.7. Scores are reported in terms of percent of sentences correctly identified. Scores observed at baseline were as follows: 65.7% correct for the new HA + training group; 56.1% correct for the experienced + training group and 60% correct for the new HA users in the control group. A one-way ANOVA indicated that there was no significant difference between groups at baseline ( $F(1,23) = .577, p=.569$ ).

The mean change score in understanding of rapid speech after 4-weeks of training was 10.33% for new HA + training, 10.07% for experienced HA + training.

Correct responses for the control group on SSI decreased by 7.4%. While both trained groups improved their comprehension on the competing speaker, a one-way repeated measures ANOVA showed that there was not a significant main effect of time within groups ( $F(1,23) = 3.27, p = .084$ ). However, the interaction of group by time was significant ( $F(2,23) = 4.01, p = .032$ ). The interaction, illustrated in Figure 4.5, shows the increase in performance by the trained groups and the decrease in performance by the control group.

*Effect Size.* Within group effect size calculations and 95% CI for the SSI test are shown in Table 4.7. Observed within group effect sizes were small in the control group ( $d = -.33$ ), but moderate ( $d = .56$ ) in the experienced training group and large in the new + training group ( $d = .83$ ) (Cohen, 1992). Confidence intervals illustrate the degree of variability within groups on this test.

Between group differences were also calculated to analyze the differences between the New HA users in the trained and control groups. Between group effect sizes with 95% confidence intervals for the SSI are shown in Table 4.5. Observed between group effect sizes for the SSI were judged to be large ( $d = 1.05$ ).

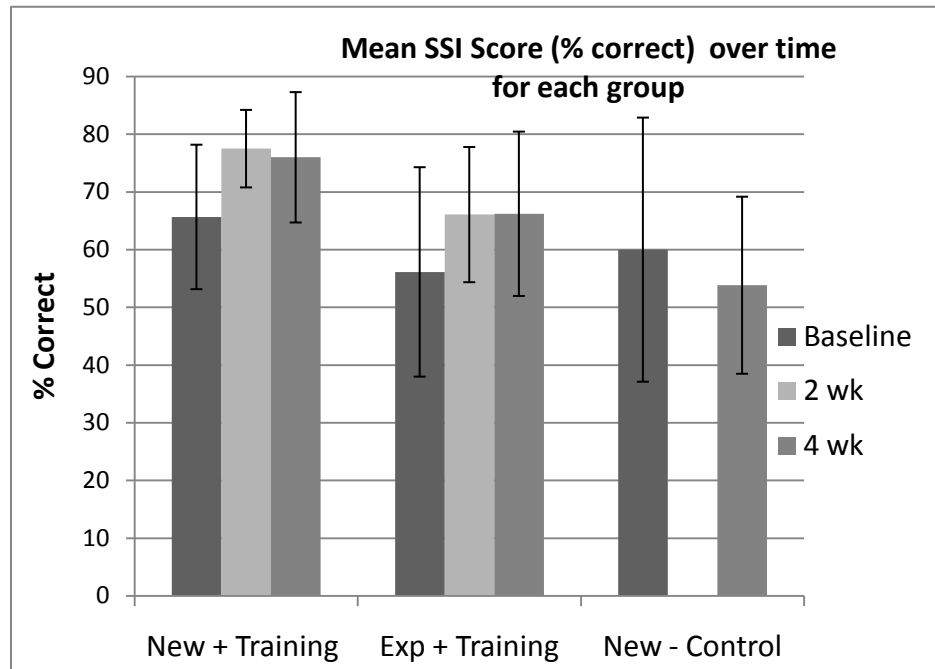
Table 4.7 Mean scores for SSI (%correct) with (SD) at baseline, after 2-weeks and after 4-weeks of training. Change scores and within group effect sizes (from baseline to 2-weeks and baseline to 4-weeks) with 95% CI for each group.

	<b>New + Training</b>		<b>Exp + Training</b>		<b>New – Control</b>	
	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>
Baseline	65.67	12.51	56.1	18.1	60	22.0
2-wks	77.0	6.32	66.0	11.7	DNT	DNT
4-wks	76.0	11.3	66.2	14.2	53.8	15.3
<u>Change</u>						
Base-4 wks	10.33	8.82	10.07	13.6	-7.4	16.8
<u>Within Group Effect Size</u>		<b>95% CI</b>		<b>95% CI</b>		<b>95% CI</b>
Base -2-wks	.90	(9.96)	.55	(9.4)	DNT	DNT
Base -4-wks	.83	(9.96)	.56	(9.4)	-.33	(17.58)

*Wks = weeks*

*DNT = Did not test control group at 2-week interval.*

Figure 4.5 Mean scores for Synthetic Sentence Identification (SSI) at baseline, 2-weeks, and 4-weeks after training for each group. Error bars represent 1 standard deviation. Higher scores represent better ability to understand rapid speech.



*Question 2*

Is there a difference in speech understanding in noise after 2-weeks of training compared to 4-weeks of training between the groups?

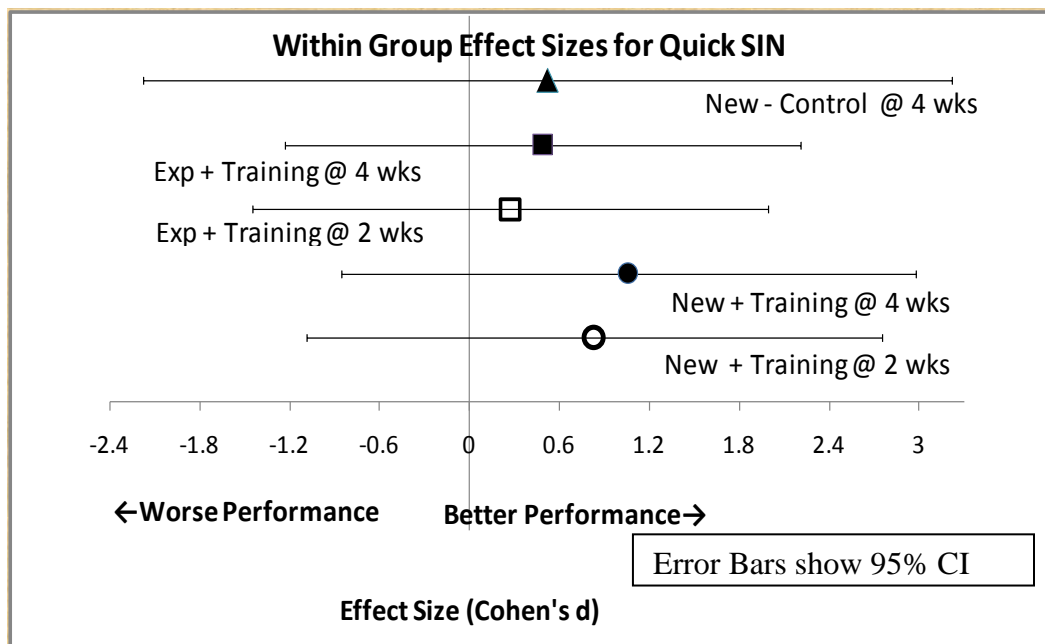
This question essentially addresses the issue of training duration for each population by asking how treatment differences change over time after 2-weeks of training compared to 4-weeks of training based on the Quick SIN test. The null hypothesis was that there were no differences in performance between groups based on the Quick SIN test after 2-weeks compared to 4-weeks of training.

The overall change in dB SNR for each trained group over time is presented in Table 4.4. A repeated measures ANOVA on the mean change in dB SNR scores revealed a significant within subjects effect for ‘time’ ( $F(2, 36) = 13.6, p < .00$ ). Post-hoc tests with linear contrasts were used to compare time-points (baseline to 2-week, 2-week to 4-week and baseline to 4-week) for the trained groups. Linear contrasts indicated that

participants in the training groups showed a significant improvement in dB SNR score after 2-weeks of training compared to baseline  $F(1,18) = 11.016, p=.004$  and after 4-weeks of training ( $F(1,18) = 26.22, p<.000$ ). Post-hoc measures also showed that there was no difference between the New + Training and Experienced + Training groups over time ( $F(1,18)=1.31, p=.266$ ). New HA users in the control group also demonstrated improvement in dB SNR (1.8 dB,  $SD = 1.64$ ) between baseline and 4-weeks. However, they were not included in this analysis because they were not seen at 2-weeks.

*Effect Size.* To further illustrate how performance changed over time, the within group effect sizes from Table 4.4 were plotted and are illustrated in Figure 4.6. New HA users + Training demonstrated large effect sizes after 2-weeks of training ( $d=.83$ ) and after 4-weeks of training ( $d=1.08$ ). In contrast, experienced HA users demonstrated small effect sizes after 2-weeks of training ( $d=.27$ ), but moderate ( $d=.48$ ) effect sizes after 4-weeks of training. The control group was also observed to show moderate effect size ( $d=.52$ ) at the 4-week follow-up (Cohen, 1992). Confidence intervals illustrate the degree of variability within groups on this test.

Figure 4.6 The within group ES for mean change in dB SNR based on Quick SIN for each group after 2 and 4-weeks of training. The unpooled standard deviation from baseline for each group was used to calculate ES.





### *Question 3*

Does the use of a home auditory training program lead to changes in perceived functional hearing abilities in daily life by adults who are new and experienced HA users compared to those who do not complete the training?

This question investigated the role of the participants' perception of functional improvement in daily life related to their hearing abilities both before after training. This question was addressed by evaluating data from two subscales of the SSQ: Hearing Speech and Other Qualities of Hearing. The null hypothesis tested that there was no difference in relative scores on each subscale of the SSQ between groups from baseline to 4-weeks. Scores on the SSQ range from one to ten. The higher the score on the SSQ, the greater the perception of functional ability during communication and daily listening activities.

A one-way ANOVA indicated that there were no significant differences between groups at baseline for either the Hearing Speech or Qualities subscales. Results obtained after training are shown in Tables 4.8a and 4.8b respectively. A repeated measures ANOVA indicated a significant difference for the main effect of "time" between baseline to 4-weeks about the perception of hearing abilities for the Hearing Speech subscale ( $F(1,23) = 8.41, p = .008$ ). Similarly, there was also a significant difference for the main effect of "time" between baseline to 4-weeks relative to the Qualities of Hearing subscale ( $F(1,23) = 8.42, p = .008$ ). Post hoc tests indicated that there were no significant differences between groups for the Hearing Speech subscale ( $F(2,23) = 3.162, p = .06$ ) or the Qualities of Hearing ( $F(2, 23) = 1.1, p = .334$ ). These results are plotted in Figure 4.7a and Figure 4.7b respectively.

*Effect Size.* Effect size calculations and 95% CI for the Hearing Speech and Qualities of Hearing subscales of the SSQ, are shown in Table 4.8a and 4.8b.

Within group ES were small for the Hearing Speech subscale in experienced + training group ( $d = .36$ ) and negligible in the control group ( $d = -.01$ ), but large ( $d = 1.0$ ) in the New+ Training group (Cohen, 1992). Observed within group ES for the Qualities of Hearing were small in the control group ( $d = .21$ ), but large ( $d = .7$  to  $.89$ ) in both trained groups. Confidence intervals illustrate the degree of variability within groups on this test.

To further analyze differences between the new HA users in the trained and control groups, between group effect sizes were calculated as previously described. Between group effect sizes with 95% confidence intervals for the Hearing Speech and Qualities of Hearing subscales of the SSQ are shown in Table 4.5. Observed between group effect sizes were judged to be large for both the Hearing Speech subscale ( $d=1.52$ ) and the Qualities of Hearing subscale ( $d=.83$ ).

Table 4.8a Mean relative values (SD) for Hearing Speech subscale on the SSQ for each group from baseline to 4-weeks. Change scores and within group effect sizes (from baseline to 4-weeks) with 95% CI for each group

	<b>New + Training</b>		<b>Exp + Training</b>		<b>New – Control</b>	
	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>
Baseline	5.1	1.4	5.2	1.4	5.47	1.9
4-weeks	6.5	1.6	5.7	1.6	5.44	2.2
<u>Change</u>						
Base – 4 wks	1.4	.87	.5	1.0	-.03	.94
<u>Within Group</u>		95%		95%		95%
<u>Effect Size</u>		CI		CI		CI
	1.0	(1.11)	.36	(.72)	-.01	(1.5)

Figure 4.7a Mean scores on Hearing Speech subscale of the SSQ at baseline and at 4-weeks.

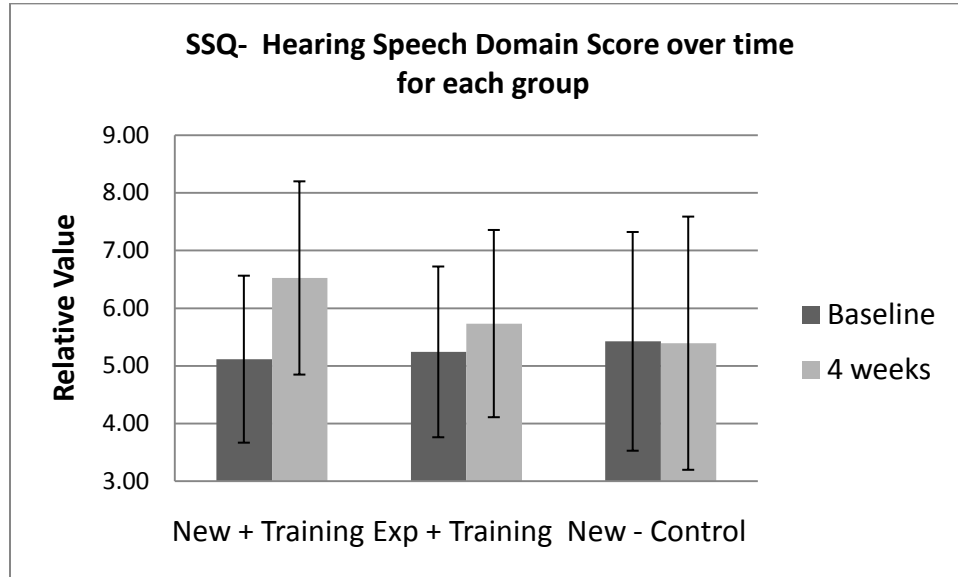
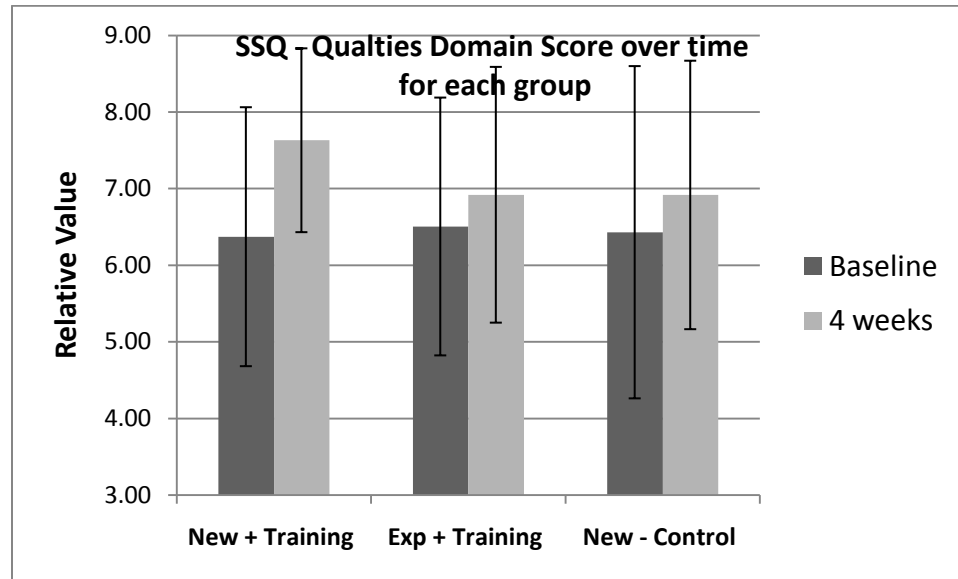


Table 4.8b Mean relative values (SD) for Qualities subscale on the SSQ for each group from baseline to 4-weeks Change scores and within group effect sizes (from baseline to 4-weeks) with 95% CI for each group.

	New + Training		Exp + Training		New – Control	
	Mean	SD	Mean	SD	Mean	SD
Baseline	6.4	1.7	6.5	1.7	6.4	2.2
4-wks	7.6	1.2	6.9	1.6	6.9	1.8
<u>Change</u>						
Base – 4 wks	1.2	1.5	.41	1.1	.48	.87
<u>Within Group</u>		95%		95%		95%
<u>Effect Size</u>		CI		CI		CI
	.7	(1.35)	.89	(.9)	.21	(1.76)

Wks = weeks

Figure 4.7b Mean scores on Qualities of Hearing subscale of the SSQ at baseline and at 4-weeks.



#### Question 4

Is there a difference in perception of benefit from treatment based on self assessment between new and experienced users?

To evaluate the overall benefit from treatment between new and experienced users, this question evaluated differences between the trained groups (new and experienced HA users) on the IOI- AI. Scores on the IOI-AI range from one to five, with higher scores suggesting greater communication function and less perception of disability. The IOI-AI was administered once after training to only the trained groups. Therefore only the trained groups could be compared directly. The overall benefit from the HAs by the new users in the control group was examined with the IOI-HA. Scores on the IOI-HA range from one to five. Results from both the IOI-AI and the IOI-HA are presented in Table 4.9. Independent samples t tests indicated a significant difference between groups about the perception of benefit from training ( $p=.017$ ) suggesting that new HA users reported greater overall benefit from training compared to the experienced

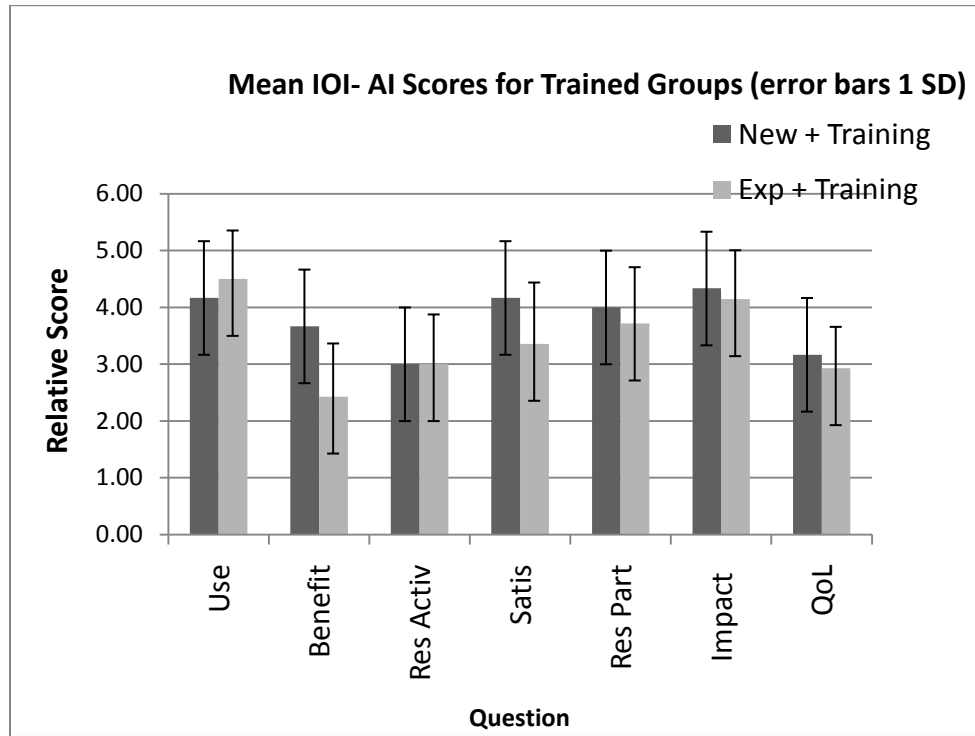
users. Figure 4.8 shows the mean values and standard deviation for each question on the IOI-AI completed by persons in the trained groups.

Table 4.9. Summary of mean scores for each question on IOI-AI for the trained groups and on IOI- HA for the control group.

Subscale	IOI- AI				IOI- HA	
	New + Training		Exp+ Training		New – Control	
	Mean	SD	Mean	SD	Mean	SD
Use	4.2	.75	4.5	.85	3.6	.81
Benefit *	3.67	1.0	2.43	.94	3.2	.81
Activity						
Limitations	3.0	.89	3.0	.87	3.3	1.0
Satisfaction	4.2	1.1	3.36	1.1	4.17	.75
Participation						
Restrictions	4.0	.63	3.71	.99	3.5	.55
Impact on						
Others	4.3	.52	4.14	.86	4.17	.41
Quality of Life	3.17	.75	2.93	.73	3.67	.81

\* Significant difference ( $p=.017$ ) for amount of benefit from training between New + Training vs Experienced + Training.

Figure 4.8 Mean (SD) IOI-AI Scores for both trained groups.



*Question 5*

Is there a relationship between working memory and the amount of benefit from training?

The fifth question related to who benefitted most from training. Of particular interest was the role of working memory. A correlation analysis was conducted to first examine the relationship between variables such as age, degree of hearing loss, working memory, duration of hearing loss, education and baseline measures for Quick SIN, SSI and Compressed Speech. Those results are presented in Table 4.10.

Table 4.10 Pearson correlations for demographic variables and dependent measures.

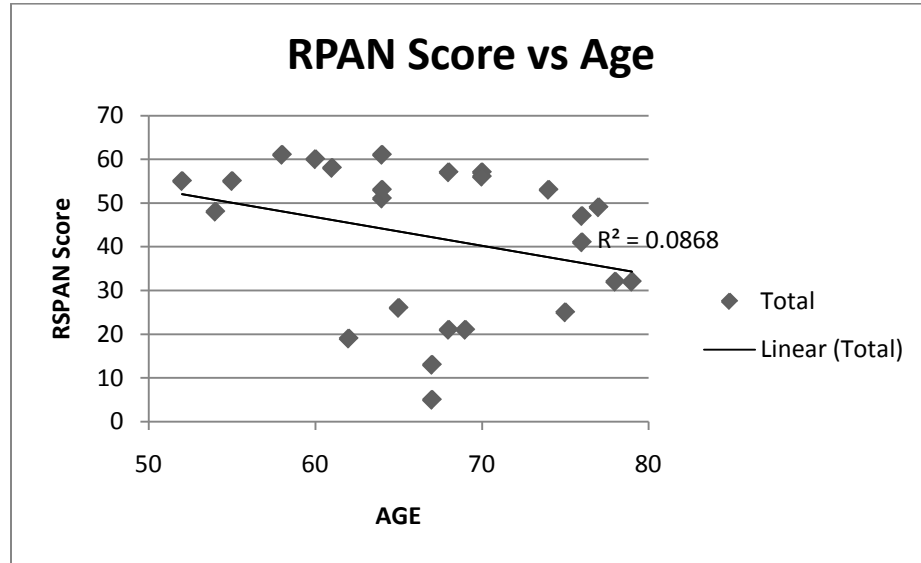
		RSPAN	Age	Length HA Use	Degree of HL	Educati on	Quick SIN Base	SSI Base
Age	Pearson Correlation	-.253						
	Sig. (2-tailed)	.222						
	N	25						
Length HA Use	Pearson Correlation	.051	-.057					
	Sig. (2-tailed)	.808	.788					
	N	25	25					
Degree of HL	Pearson Correlation	.011	.170	.574(**)				
	Sig. (2-tailed)	.957	.416	.003				
	N	25	25	25				
Educati on	Pearson Correlation	.391	.190	-.008	-.120			
	Sig. (2-tailed)	.054	.363	.969	.566			
	N	25	25	25	25			
Quick SIN Base	Pearson Correlation	.049	.200	.213	.414(*)	.080		
	Sig. (2-tailed)	.815	.338	.306	.040	.705		
	N	25	25	25	25	25		
SSI Base	Pearson Correlation	-.097	-.077	-.278	-.392	.047	-.586(**)	
	Sig. (2-tailed)	.644	.714	.178	.053	.823	.002	
	N	25	25	25	25	25	25	
Compr essed Base	Pearson Correlation	-.058	-.174	-.290	-.593(**)	-.041	-.802(**)	.557(**)
	Sig. (2-tailed)	.782	.405	.159	.002	.847	.000	.004
	N	25	25	25	25	25	25	25

\*\* Correlation is significant at the 0.01 level (2-tailed).

\* Correlation is significant at the 0.05 level (2-tailed).

While a negative trend was observed between age and (RSPAN) working memory, the Pearson correlation ( $r = -.253$ ) was not significant ( $p=.22$ ). In addition, the Pearson correlation between the baseline score of the Quick SIN and working memory was very low ( $r=.049$ ) and also not significant ( $p=.815$ ). Interestingly, the only correlation that approached significance with the RSPAN was years of education ( $r=.391$ ,  $p=.054$ ). Large individual differences on the RSPAN were observed which are illustrated in Figure 4.9.

Figure 4.9 Scatterplot of individual scores for working memory (RSPAN) vs Age. Regression line represents best fit.



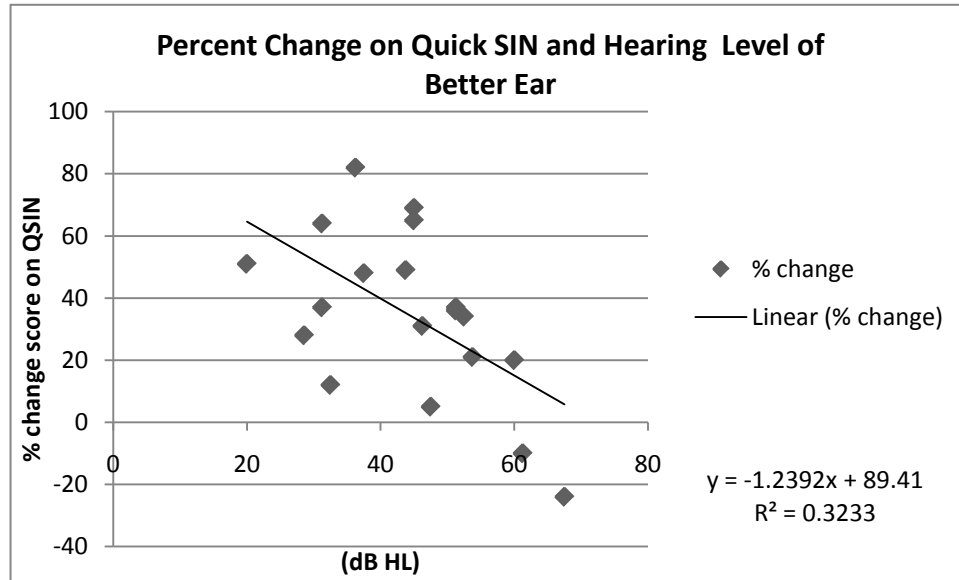
A linear regression analysis was conducted to examine the factors that may contribute to benefit from training. Stepwise variable selection was used to identify significant factors. Hearing level was the factor that predicted the most variability ( $r^2 = *.35$ ) in the benefit from training. None of the other variables entered (Quick SIN at baseline, duration of HA use, working memory, and age) significantly improved the prediction. A scatterplot for the two variables (Figure 4.10) indicates that hearing level in the better ear and percent change on the Quick SIN are linearly related such that as overall hearing level increases, the percentage of change on the Quick SIN decreased. The regression equation for predicting the overall benefit from training as measured by the Quick SIN is:

$$\text{Percent improvement on Quick SIN} = -1.239 (\text{better ear}) + 89.4$$

The 95% confidence interval for the slope, 47.26 to 131.56, does not contain the value of zero and therefore the hearing level in the better ear is significantly related to the overall percent improvement observed on the Quick SIN.



Figure 4.10. Scatterplot for hearing level as a function of percent change observed on Quick SIN for participants in training groups. Regression line represents the relationship between these two variables.



## Chapter Five: Discussion and Conclusion

This chapter will discuss the findings for each research question and hypothesis. This will be followed by a discussion of the limitations of the study, clinical implications, future directions and conclusions.

### Discussion

#### *Question 1a*

Does the use of a home auditory training program in a DVD format (for 4-weeks) result in improved speech understanding in noise for new and experienced adult HA users alike who receive the training compared to a control group of new HA users who do not receive the training?

The hypothesis for Question 1a was that in the trained group, new HA users would obtain greater improvement for understanding speech in noise than experienced HA users. Furthermore, new HA users in the trained group would also obtain greater benefit than new users in the control group.

The results from this question do not support the hypothesis related to Question 1a. In the trained group, new HA users did not obtain significantly greater improvement in speech understanding in noise compared to experienced HA users. Additionally, new HA users who completed the training did not obtain significantly greater benefit in comparison to the new HA users in the control group. The results from the ANOVA analysis demonstrate that all three participant groups improved on the speech in noise task and that there were no differences across groups. It should be noted, however, that the new HA users in the training group experienced the largest improvement in dB SNR of all groups. The additional dB SNR improvement by the new users in the training group over the control group suggests that additional improvements in speech in noise understanding are possible beyond the use of the HA alone. The improvement in dB SNR obtained by the control group may be a result of acclimatization effects from the HA (Gatehouse, 1992).

Inspection of individual data suggests one score is an outlier in the control group at 4-weeks. One individual had a significant change (more than 20 dB) in one ear on the

Verifit measures between baseline and 4-week testing. Despite efforts to adjust the presentation level of the recorded listening tasks, an unusually large reduction in dB SNR was observed (5.2 dB). Discussion revealed that this person returned to the dispensing audiologist after learning that baseline Verifit measures did not meet prescribed target levels. This individual had been counseled during the baseline session not to return to the audiologist until the conclusion of the study: therefore, inclusion of this participant is likely affecting overall results for the control group. The overall mean change from baseline to 4-weeks for the control group observed with this outlier was 1.8 dB (SD = 1.64). If this score were excluded from analysis, the control group performance would have only improved by 1.2 dB (SD = .8).

The small (1.6 dB) but significant reduction in dB SNR observed by the experienced HA users is encouraging given this sample size. Interestingly, this reduction is consistent with the reduction in dB SNR reported by Sweetow and Sabes (2006). However, the experienced user group in the Sweetow and Sabes study included users with as little as six months of HA use, whereas experienced HA users in this investigation had a minimum of 2 years of experience. One could argue that the experienced user group in this study was more experienced as indicated by length of HA use in comparison to the Sweetow and Sabes (2006) study. While a 1.6 dB reduction in SNR may seem small, the metric is logarithmic and as such, may translate into useful improvement in speech understanding. For example, an average 2.2 dB improvement in SNR was observed in adults between unaided to aided conditions (Mendel, 2007). Even a 1dB reduction in SNR is commensurate with a 6-8% improvement in percent correct scores for sentence recognition (Crandell, 1991; Wilson et al., 2007). Using this reference, a 1.6 dB SNR reduction correlates with a projected 11.2% improvement in sentence recognition in noise.

### *Question 1b*

Does the use of a home auditory training program in a DVD format (for 4-weeks) result in improved understanding of rapid speech for new and experienced adult HA users alike who receive the training compared to a control group of new HA users who do not receive the training?

The hypothesis for Question 1b was that for participants in the trained groups, new HA users would obtain greater improvement for understanding rapid speech than experienced HA users. Furthermore, new HA users in the training group would also obtain greater benefit than new users in the control group.

Results from Compressed Speech test do not support the hypothesis related to question 1b. The percentage of correct words increased from pre-test to post-test for all groups on the Compressed Speech test. There are several possible explanations for this. First, large standard deviations were observed on this measure which makes finding true differences difficult given the small sample size. In addition, most of the training time in the LACE™ training program is allocated to speech in noise training with a smaller amount of time allocated for training with rapid speech. This may explain why participants had relatively small gains in this area. Another possible reason is that the training format in the rapid speech section of LACE™ is sentence based, while the assessment format is word based. Generally training on a specific task shows improvement on comparable tasks but does not generalize to other types of tasks (Burk & Humes, 2007). Anecdotally, several participants reported that the rapid speech task was more difficult than listening in noise. If this is true, it may be that training on rapid speech may take more time to observe an effect than is provided by the present version of LACE™.

#### *Question 1c*

Does the use of a home auditory training program in a DVD format (for 4-weeks) result in improved understanding of competing speech for new and experienced adult HA users alike who receive the training compared to a control group of new HA users who do not receive the training?

The hypothesis for Question 1c was that for participants in the trained groups, new HA users would obtain greater improvement for understanding competing speakers than experienced HA users. Furthermore, new HA users in the training group would also obtain greater improvement than new users in the control group.

The results from the SSI do not support the hypothesis related to Question 1c. There was not a significant difference between trained groups in their ability to identify

competing sentences because performance improved by approximately 10% in both groups. While a significant interaction was observed with the ANOVA analysis, no statistical group differences were found.

Overall mean levels for the SSI at baseline are similar to those obtained by Dubno and Dirks (1983) on a population of older adults. Large individual variability was observed on this task in their study as well as in the present study. This variability may have made it difficult to observe significant differences between groups.

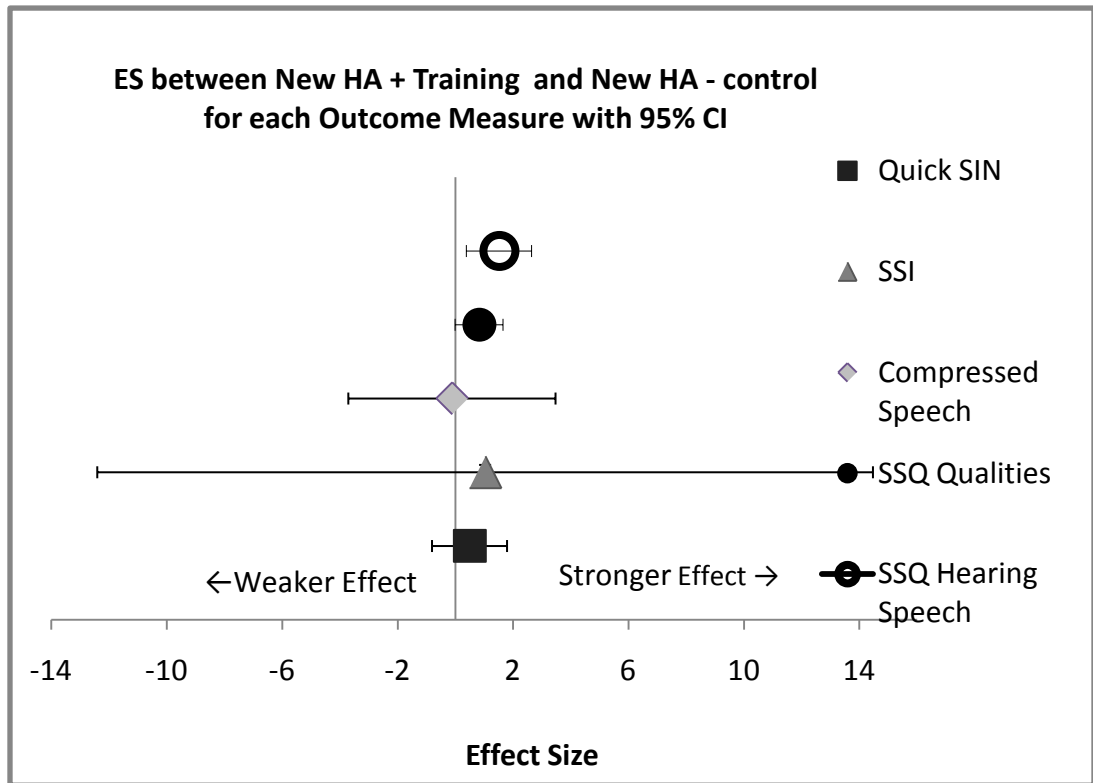
The trends observed here are interesting because both trained groups improved, yet the control group declined. Additional participants may help clarify the actual effect of training on this very difficult listening skill which has been described as an informational masking task (Schneider et al., 2007). Informational masking tasks are more complex because listeners have to first separate the peripheral signal into distinct auditory streams, and then focus attention on the target voice. Next listeners have to extract meaning from the target voice and finally inhibit processing of the unwanted auditory voice. Interestingly, participants in this study consistently reported that the competing speaker tasks (both during training and assessments) were more difficult than listening in background babble because they found it challenging to inhibit relatively meaningful information. Previous research has suggested that the more complex the listening task, the greater the amount of training time needed (Watson, 1980; Larsby et al., 2005). Given that the nature of the task in the SSI is challenging, additional training beyond what is provided in the current DVD version of LACE™ may be necessary before observing more consistent effects.

In sum, it is likely that between group differences for each measure discussed in each section of Question 1, were not observed due to insufficient power. This is supported by the result of the ES analyses. ES is a useful measure of the practical significance of treatment effects as it measures the magnitude of the relationship between the independent and dependent variables and is not influenced by sample size (Cohen, 1992). The confidence interval (CI) around the effect size is also useful in interpreting treatment effects because it suggests how probable it is that the real effect size is zero. For example, Figure 5.1 illustrates the 95% CI for each assessment between new users in the treatment and control groups. The 95% CI for the Quick SIN and SSQ tests are small,

which is in part due to the range of scores possible on each scale. These scores range from 0 to 5 on the SSQ and -2 to +12 on the Quick SIN. In contrast, the 95% CI for the SSI and Compressed Speech test are larger than those observed for the Quick SIN and SSQ, in part because these tests are scored in terms of percent correct and range from 0 to 100%.

Equally important to consider, is whether or not the confidence interval crosses zero. The fact that a confidence interval crosses zero, indicates uncertainty as to the true effect of the intervention. In contrast, when the confidence interval does not cross zero, this indicates more certainty that a true effect occurred. The 95% CI for the Quick SIN, Compressed Speech and the SSI all cross zero whereas it does not cross zero for either subscale of the SSQ.

Figure 5.1 Between group (New + Training and New – Control) ES with 95% Confidence Intervals for each outcome measure.



## *Question 2*

Is there a difference in performance after 2-weeks of training compared to 4-weeks of training?

The hypothesis for the second question was that a significant improvement in speech understanding in noise would occur after the first 2-weeks of training for new and experienced users and would essentially plateau after the additional 2-weeks of training.

The results from this question partially support hypothesis 2. New HA users + training demonstrated significant gains in speech understanding after 2-weeks of training. The additional 2-weeks of training did not result in additional improvements for understanding speech in noise for the new users. In contrast, the experienced users did not obtain any significant improvement after 2-weeks of training, but did show a significant training effect after 4-weeks. While the data reflects individual differences related to benefit, it appears that the 2-weeks of LACE™ training may be adequate for new HA users, but inadequate for experienced HA users.

This “one size doesn’t fit all” result observed from this training study is not surprising when considered in the context of duration of hearing aid use between groups. For example, Sharma and colleagues (2002) have clearly demonstrated the effect of duration of hearing loss on outcomes for children with cochlear implants. Specifically they found that the shorter the period of deprivation, the more efficient the functioning of the central auditory nervous system as reflected in electrophysiological tests. Furthermore, Sharma and colleagues have argued that there is a sensitive period during which optimal benefits may be observed from implantation. While the concept of critical window typically applies to discussions about the developmental period in young children, the neural underpinnings of a critical window have been well studied (Levi-Montalcini, 1949; Koerber, Pfeiffer, Warr, & Kiang, 1966; Kral, Tillein, Heid, Hartmann, & Klinke, 2005). Together these studies imply that there is a huge potential for neural plasticity based on the experiences of sensory stimulation provided at an early age.

While the present study examined training effects in an adult population, the principles of neural plasticity still apply. Previous research with adults suggests that adaptation within the central auditory nervous system occurs not only after periods of deprivation and during development, but also after the fitting of sensory devices. For

example, clinical studies with adults have shown improvement in word recognition ability after fitting with amplification (Silman et al., 1984). This implies that adults are able to recover some auditory function after use of sensory devices. Much of the improvement is thought to occur within the first 6 to 12 weeks of HA use and then plateau (Gatehouse, 1989,1992). In adults with cochlear implants, similar time course issues exist as persons adapt to novel electrical stimulation. The time course of this adaptation appears to vary (Luntz, Shpak, & Weiss, 2005). For example, rapid improvements are often observed within the first few months of implant use with slower continued improvement up to 2 years after the initial fitting, with minimal improvement beyond 2 years of implant use. Both HA acclimatization and adaptation to electrical stimulation with implants are examples of auditory plasticity in adults that occurs after experience with sensory stimulation. Such conditions could be described as evidence that an optimal window exists during which training should be paired with sensory management to obtain best the possible outcomes. The findings from this study support the concept of an optimal window because new HA users who had less experience with sensory stimulation appeared to obtain better outcomes after training than persons with longer durations of HA use. This finding was supported by the effect size analysis that showed large effect sizes for new HA users and small effect sizes for experienced users after 2-weeks of training. While the term “critical window” may best describe the importance of temporal issues with children, “optimal training window” may better describe the importance of combining training soon after placement of sensory management for adults. In other words, it may be very important for new HA users to complete training soon after receiving amplification, rather than after extensive HA use.

### *Question 3*

Does the use of a home auditory training program lead to changes in perceived functional hearing abilities in daily life by adults who are new and experienced HA users compared to those who do complete the training?

The hypothesis for this third question was that both new and experienced users in the trained groups would report improvement in functional listening abilities and that new



HA users would report improved functional listening abilities in comparison to the new HA users in the control group.

Results from the SSQ partially support this hypothesis. There was a significant improvement for both subscales of the SSQ between baseline and 4-weeks. However, there was not a significant difference between groups from baseline to 4-weeks for either the Hearing Speech or Qualities subscale. While there were not statistically significant differences between groups, the observed p-value approached significance ( $p=.06$ ) for post-hoc measures on the Hearing Speech subscale. This would suggest communication function improved more in both trained groups compared to the control group which is illustrated in Figure 4.7a. The within group ES analysis supports these findings in that larger ES were observed for new users in the training group compared to medium and small effects for the experienced and control groups. With a larger sample, these trends may be more clearly observed.

On the SSQ, changes in one-unit intervals are considered significant (Noble & Gatehouse, 2006). All of the new HA users in the treatment group reported improvement on both the Hearing Speech and Qualities of Hearing subscale from baseline to 4-weeks. In contrast, only 35% of the experienced HA users reported improvement on one of the subscales. Results from the experienced users in this study are in contrast to the findings from the Sweetow and Sabes (2006) study where a computer based training program was used to deliver the training. They found improvement in communication function based on the Hearing Handicap Inventory for the Elderly (HHIE) (Ventry & Weinstein, 1982) which may be more sensitive to training effects than the SSQ used in this study. While training duration in both studies was the same, the content varied slightly between the computer training program and the DVD as was described earlier. While new users perceived greater functional change, the experienced users did not, which suggests that experienced users may need additional or more varied training if the goal is to alter an individual's perception of communication function.

Changes in the perception of listening effort after HA fitting have been previously published (Larsby et al., 2005; Noble & Gatehouse, 2006). The improvement in Qualities of Hearing subscale of the SSQ after training for new users observed in this study may be linked to the questions that targeted effortful listening. As discussed earlier, the

hypothesis of effortful listening has been articulated by Pichora-Fuller and Singh (2006). They argue that listening is particularly challenging for older adults with hearing loss because additional cognitive resources are needed to process language in less than ideal conditions. Furthermore, the allocation of these additional resources to processing language in difficult listening environments in turn reduces the number of resources available for storage and memory. The improvement noted in the present study may be consistent with the hypothesis that there is a reduction in effortful listening after training.

#### *Question 4*

Is there a difference in perception of benefit from treatment based on self assessment between new and experienced users?

The hypothesis related to the fourth question was that greater benefit from training would be reported from the new users compared to the experienced users.

Results from the IOI-AI support this hypothesis. New HA users reported greater perceived benefit after training compared to the experienced users. The question about perceived benefit asks, “*Think about the situation where you most wanted to hear better before doing the LACE™ training. Over the past 2-weeks, how much has the LACE™ training helped in that situation?*” Significant differences between trained groups were not found on objective measures, which make this difference in perception of benefit intriguing. To address this, a comparison was made between the present study and another training study where both new and experienced HA users who participated in a DVD format home education program (Kramer et al., 2005). The intervention in the Kramer and colleagues study focused on teaching communication strategies. Participants in both the Kramer study and the present study reported significant changes in benefit from training. Furthermore, the amount of benefit reported from persons using LACE™ appears to be consistent with the findings reported by participants in the study by Kramer and colleagues (2005). Together these studies suggest that effective training can occur in a home setting. This is encouraging for individuals with hearing loss and HAs because it underscores the potential that additional benefit exists from training that occurs at home rather than in a clinic.

An alternative argument about these findings is that the difference between groups in perceived benefit relates to the communication tips imbedded throughout the LACE™ training. Previous research has indicated that communication strategies incorporated into aural rehabilitation programs contributes to reduction in perceived handicap and greater satisfaction with amplification (Hawkins, 2005). In this study, experienced users would have more knowledge about communication strategies simply because they have already developed these strategies over time. Consequently, they may not perceive as much benefit in comparison to new users.

Previous research has suggested that effects from aural rehabilitation may vary for new and experienced HA users (Kramer et al., 2005). The findings in this study are consistent with that notion and reinforce the concept that the optimal window for training may in fact be soon after the HA fitting. However, some previous research suggests that perceived benefit from amplification declines over time (Chisolm, Abrams, & McArdle, 2004). If this is true, then this general decline in perception of benefit from HAs may have influenced the experienced users overall perception of benefit. While the question in this study clearly relates to benefit from the training, the HA and the training are likely inextricable linked which may be difficult to separate in the users' minds. While it is not completely clear how much of the benefit is attributable to the training and how much is actually from the HA, the trends warrant further investigation.

#### *Question 5*

Is there a relationship between working memory and the amount of benefit from training? Specifically, does working memory contribute to predicting outcomes from training?

The hypothesis for this fifth question was that working memory would contribute significantly to explaining the amount of benefit obtained by participants in the training groups. Results for this question do not support the proposed hypothesis that there would be a significant difference in the percentage of variance explained by regression analysis for a model that includes working memory and a model that does not include working memory.

Results from the correlational analysis were surprising. It is well accepted in aging research that working memory decreases with age. The weak negative relationship ( $r = -.253, p = .222$ ) between working memory and age observed in the present study is inconsistent with previous research (Sanders et al., 1980; Hamm & Hasher, 1992; Salthouse & Coon, 1993). Therefore, results from the automated RSPAN Test in this population of adults from 50-80 are interesting. It is possible that the RSPAN Test is not sensitive to the age related changes that are typically observed. Some participants reported that this task was challenging. If the task was too challenging, then participants could have become unmotivated to complete the task with the required effort and concentration. If this actually occurred, then RSPAN scores would have been lower than those obtained in the present study.

Another possibility is that the high level of education reported by participants in this study affected working memory results. In other words, the working memory results observed did not show evidence of an age effect because of the high levels of education obtained by many participants. For example, previous research has examined the effect of age on central auditory function and reported that reading span scores declined with age (Hallgren, Larsby, Lyxell, & Arlinger, 2001). These researchers observed that older adults obtained an average of 41% correct response rate on the reading span test compared to 61% correct response rate for the younger adult group. The percent correct values observed in the present study ranged between 55-58% correct for all three groups. This suggests that the RSPAN Test scores observed in this study were higher than those reported by the Hallgren et al. (2001) study using a similar reading span task in a similar target population. This finding suggests that the higher education levels of participants in this study seemed to result in larger working memory spans than expected for their age, which may explain the findings observed on the RSPAN Test.

Furthermore, a strong relationship between the Quick SIN score at baseline (as reported in dB SNR) and the RSPAN Test was also expected. The non significant ( $r = .049, p = .815$ ) relationship between SNR at baseline and the RSPAN Test was also surprising in light of previous research (Lunner, 2003; Foo, Rudner, Ronnberg, & Lunner, 2007; Akeroyd, 2008). For example, Lunner (2003) reported a robust correlation ( $r = -.61$ ) between reading span and speech recognition in noise. He further concluded

that working memory, as reflected by the RSPAN Test, accounted for 40% of the variance in the obtained speech recognition thresholds in noise. In the present study, this lack of a relationship between working memory and age was not expected. However, no normative data are available for the RSPAN Test in older adults. While this cognitive measure was not sensitive to age differences in this study, it may be sensitive in a broader population of participants.

The absence of these expected associations between working memory and age, as well as working memory and speech recognition in noise, may explain why working memory did not significantly contribute to the variance in the regression analysis as hypothesized given the small sample size. The fact that a relationship was not observed between the amount of benefit from training and working memory does not mean that one does not exist. However, it does suggest that further research is needed with a larger sample size and inclusion of persons with more varied levels of education.

The results from the regression analysis suggested that hearing level was the best predictor of training outcome such that persons with better hearing ( $\leq 60$  dB HL) were observed to obtain greater improvement in ability to understand speech in noise compared to persons with worse hearing ( $> 60$  dB HL). As mentioned earlier, the new HA user + training group had significantly better hearing than the experienced HA user + training group. Therefore, it is unclear if the better training outcomes are attributable to the fact that these persons were new HA users or because they had better hearing. Given that the correlation between hearing level and the length of HA use was significant ( $r = .594, p = .001$ ), there is clearly some shared variance between these variables. The squared correlation of this relationship ( $r^2 = .35$ ) indicates that approximately 35% of the variance is shared between hearing level and length of HA use. The redundancy in variance between these two variables makes interpretation of training effects difficult. Therefore, readers must be careful to not over interpret the trends observed in this study. Additional research including both new HA users with more hearing loss and experienced HA users with less hearing loss, would help to resolve this issue.

### *Limitations*

As with any research study, various limitations were encountered during the course of this project.

The small sample size is a primary limitation because it affected the power of this study. The standard power rate used by most researchers is .80; the power rate in this study was .60. This suggests that insignificant findings (e.g., results in Question 1 or Question 2) may be the result of a Type II error (false negative) whereby researchers failed to reject the null hypothesis when the null was false. Given that a Type II error is possible, a larger sample size is needed to determine if true differences exist between experienced and new HA. The ES calculations between and within groups are encouraging and suggest that some difference does exist so that ideally, with additional participants, these differences can be more confidently detected.

Technical problems were reported by 25% of participants in this study. The technical problems resulted in either a delay in training or a slight modification in training procedure. Some of these problems could be resolved through a phone consult with the primary investigator and others took several days to resolve. The types of problems encountered ranged from reports of the DVD responding slowly, to completely freezing, as well as not being able to start the DVD. In some situations, participants restarted the DVD at the section where it became stuck and resumed training. Some participants cleaned the DVD which solved the problem. Other participants (n=5) reported that the freezing only occurred on the competing speaker condition. Replacement DVDs or DVD players were provided for participants with these problems. One participant needed to replace the battery in the remote control. Such training delays did not appear to greatly influence participant outcome. One participant was simply unable to manipulate the remote and DVD. This was solved by having her significant other operate the remote, while she completed the training. Using this accommodation, this participant still obtained over a 5 dB reduction in her dB SNR score. This modification to training protocol did not appear to affect participant outcome.

An additional limitation is that the control group of participants was evaluated twice (at baseline and 4-weeks), while the training groups of participants were evaluated three times (baseline, 2-weeks, and 4-weeks). Therefore the additional exposure to

repeated testing by the trained group may be a threat to internal validity of the study. This method of evaluation was selected for two reasons. First there were practical aspects involved with scheduling participants to come to the University of Kentucky campus. Many individuals were older adults and reported apprehension with multiple visits to campus. Second, in the design used in this study, participants could not be blinded about whether or not they were completing the training. Therefore, researchers made an assumption that if they were not receiving the training, that they were not likely to improve and therefore they did not need to be evaluated until the final 4-week session.

True participant compliance with training is difficult to measure in this study because all training was conducted at home. The DVD version of LACE™ does not record training time on task. While participants reported that they completed either all or most of the training sessions, it is possible that they did not complete as many as they reported. The participant, who was eliminated from the analysis for not completing an adequate amount of training, reported that he had not completed the training when asked. Therefore, such considerations of non-compliance seem remote, since participants in general want to improve their own listening abilities in noise and are motivated to do so. Furthermore, one could argue that if participants did not complete the training, the measured training effects obtained here may be underestimated.

Variation in HA function across assessment visits was also a limitation in this study. While overall results with Verifit suggested that most persons were not functioning with recommended gain based on deviations from ideal target values, variation between assessment visits did not vary except in one circumstance. One participant's Verifit results indicated that a HA response changed significantly between baseline and 4-weeks. At baseline, this participant observed that his Verifit response deviated more than 20 dB from prescribed target values particularly in the low frequencies. As previously discussed, after learning about the deviation, the participant returned to the dispensing audiologist for a HA check before the 4-week return visit. As a result of the adjustment, he obtained a larger than anticipated improvement in his SNR score on the Quick SIN (from +10.0 dB SNR to +5.4 dB SNR). The magnitude of improvement of this one participant likely skewed results for the entire control group.

There is potential for experimenter bias in this study because the primary investigator administered all assessments. She had knowledge and background information about each participant as well as to which group they had been assigned. Therefore, using the primary researcher from the study presents threats to both internal validity (e.g., the researcher may modify behavior in order to obtain certain results) and external validity (e.g., the results may generalize only to persons in this study and not to a broader population of HA user from the general public). Future studies should include a method for additional personnel to perform assessments so that they are blinded to group assignment.

To extend training beyond 2-weeks, participants in the training groups listened to the same material during the 2-week and 4-week assessments. The reason for this was because the LACE™ DVD training program is a fixed program, composed of 10 lessons, which can be completed within 2-weeks. Researchers were unsure if 2-weeks of training was adequate training time to observe a difference and hence the reason that LACE™ training was extended 2-weeks so that participants could train longer than the original 2-week protocol.

Finally, the population in this study was a well educated group and, therefore, does not represent a typical HA population. Several persons (n= 13) held degrees of a master's level or above. Thus, it is not clear if these results would be generalized to the typical HA population in terms of training, compliance and outcomes.

### *Implications for Training*

The trends observed here provide several clinical implications. First, the findings obtained suggest that some additional benefit, beyond the HA itself, is possible. That new HA users reported greater benefit from training compared to experienced HA users suggests that the timing of when to begin training may be very important. While the magnitude of benefit cannot be guaranteed, benefits from such training may also contribute to reduced HA returns (Martin, 2007). Second, effect size calculations suggest that new users obtained improvement from training before experienced users. While additional research is needed to fully understand the time course over which this benefit occurs, it seems reasonable that experienced HA users may not demonstrate



improvements after only 2-weeks of training with the LACE™ DVD. Therefore, if an individual does not demonstrate improvement after 2-weeks of training, clinicians could recommend that training be extended beyond that prescriptive timeframe. The fact that experienced HA users may obtain any benefit at all is encouraging and provides an alternative tool for rehabilitation. Third, implementation of the DVD version of the LACE™ training program at home for adults was feasible and worked well for most participants. Participants could operate the program in their own home environment and most technical problems could be addressed with minimal time delay. As such, the DVD version appears to require little time from clinicians in terms of troubleshooting equipment or training on how to use the program.

#### *Future Research Directions*

More participants are needed to support the trends observed here. The premise of this study was that new HA users would achieve greater benefit from training than experienced HA users. While these findings were not confirmed via hypothesis testing, the trends observed based on effect size analysis suggest otherwise. Therefore, expanding this study with larger numbers of participants to obtain adequate power may help illustrate a clearer picture about the benefits of LACE™ training.

Many experienced users commented that they wished that they could have obtained this training after they first received HAs. This observation conveys an interesting point and suggests that the simple question about when training should begin could also be explored. Stecker and colleagues (2006) attempted to answer a similar question. They examined the effects of a research designed home training program in new HA users who either received the training immediately after being fit with aids or eight weeks later. They found that both groups of new HA users obtained similar benefits and concluded that training effects were possible whether or not training occurred immediately or up to eight weeks later. The findings in this study reflected outcomes for HA with more varied spans of HA use, particularly in the experienced HA user group which ranged from 4- 50 years. By dividing this group into smaller ranges of HA use (e.g., 2-10 years, 10-20 years), additional knowledge about the precise time period during which benefit can be observed from training would be helpful for clinicians. Determining

whether or not “earlier” training is more beneficial than “later” training would be a very important clinical question to answer.

Treatment compliance is likely a multi-faceted complex behavior. As such, it may be influenced by many factors including motivation (Brewer et al., 2003), self efficacy (Allison & Keller, 2004) and even personality (Cox, Alexander, & Gray, 2007). In an effort to improve compliance with training in this study, participants submitted scorecards with interim data clearly recorded. Of the 26 participants, 88% of participants completed all 20 lessons with the remaining 12% of participants completing at least 16 of the 20 lessons. However, if participants had not completed the training, the moderate and large effect sizes reported previously may not have been observed. Technological advances such as the LACE™ computer training program used by Henderson-Sabes and Sweetow (2007). The trade-off is that a more technologically advanced system that logs training time may not be as user friendly as the DVD format is for older adults. While use of a computer training program would solve this problem, it may create user problems for older adults.

For audiologists to fully embrace the notion about training after HA fitting, they need to better understand the difference in performance between the HA alone and the HA plus training. While this research attempted to examine that difference, additional research is needed with both treatment and control groups to more fully appreciate the advantage that training provides. The new users + training group showed progress after only 2-weeks of training. However, the control group was not evaluated after 2-weeks of training. Thus, a follow-up study using a 2-week training paradigm for new HA users would be interesting so that a more direct comparison can be made between the groups.

Abrams and colleagues (2002) described a cost-utility analysis to demonstrate the cost-effectiveness of two treatment approaches for adults with HAs. They compared how a HA + aural rehabilitation compared to HA alone in terms of the cost and the quality of life. These researchers concluded that the HA + aural rehabilitation was a more cost-effective treatment approach than the HA alone. A similar study to illustrate how participants perform with the HA alone compared to the HA +training using the LACE™ DVD could be conducted to determine the cost-effectiveness of the LACE™ DVD

training. This type of research may provide the needed evidence to convince clinicians to recommend additional training for their HA patients routinely.

Another issue that would be interesting to examine would be to incorporate an electrophysiological measure that reflect cortical activity such as the P300 in noise. Electrophysiological measures showing a reduction in the absolute latencies of waveforms, may suggest that true processing ability in noise has changed. Such findings may help our profession better understand if true cortical change occurred or if participants learned strategies for listening which indirectly affected listening behaviors. The improvements observed in this study may be related to behavioral adaptations and increased awareness about understanding in noise, as anecdotally noted from five different participants (e.g., “I really learned how hard I have to focus if I want to understand in noise”). Regardless of the precise nature of change that has occurred, functionally, persons who participated in this training program improved their ability to listen in noise and this is ultimately what is most important to individuals with hearing loss.

The relationship between working memory and benefit from training needs further exploration. While findings in this study did not expand our understanding about how cognition might affect outcome from training, this does not mean that there is no relationship. It is undoubtedly easier for us as audiologists to ignore the effects of cognitive function on our treatments, but its existence cannot be denied in light of mounting evidence as previously discussed. In fact, a more systematic and rigorous approach has been discussed by others who have called for exploration into the interdisciplinary study of Cognitive Hearing Science (Arlinger, Lunner, Lyxell, & Pichora-Fuller, 2009).

Who actually benefits from training is of particular clinical interest because it provides additional information that can be used in counseling. Previous studies suggest that persons with greater hearing losses or greater perception of hearing handicap seemed to benefit most from training (Henderson-Sabes & Sweetow, 2007; Humes et al., 2009). In contrast, in this study, persons with hearing losses exceeding 60 dB actually achieved smaller gains from the LACE™ DVD training. In fact, performance actually declined in the two persons with the greatest hearing losses. This could be due to the fact that there

was less variety in sentence stimuli available in the DVD training program compared to the computer training program used by Henderson-Sabes & Sweetow (2007). This study However, a more likely explanation of the observed training effects may relate to audibility of speech. Verifit measures clearly showed that deviations from ideal targets were commonly observed in both groups. However, the effect of these deviations negatively impacted the audibility of speech for persons with greater hearing loss. As discussed previously, the significant difference in hearing level between the training groups confounds the researcher's ability to draw definitive conclusions about who actually benefits from training. Until additional persons who are new HA users with greater hearing loss and experienced HA users with less hearing loss are included in such research, we cannot be certain if the training outcomes are due to the fact that persons had better hearing or because they were new HA users.

## Conclusions

### *Main Findings*

The main purpose of this study was to examine the behavioral effects of the LACE™ DVD training program. The main finding was that participants in both groups seemed to benefit based on objective tests and by self report. While significant differences between groups could not be confirmed with hypothesis testing, larger training effects seem to be possible for new HA users compared to experienced HA users. These findings need to be explored with a larger sample to verify the trends observed.

### *Differential Effects*

The suggestion that differential effects from intervention may be observed has been previously discussed (Kramer et al., 2005). New HA users clearly showed improvement before experienced HA users. This was interesting because it suggests that auditory training affects acclimatization to HAs particularly for new users. Robinson and Summerfield (1996) suggest that there are two issues pertaining to acclimatization and auditory training. The first is to determine if auditory training speeds the process of acclimatization. The second is to determine the magnitude of benefit from training. The preliminary findings from this study suggest that the LACE™ training for new HA users may speed the process of acclimatization because new HA users who completed the

training demonstrated larger training effects new HA users in the control group after 4 weeks. What remains unclear is whether or not the new HA users in the control group would have eventually reached the same performance levels as the new HA users in the training group. For experienced HA users, the fact that improvement is still possible even after several years of HA use is very encouraging. However, not all experienced users obtained benefit. One individual in this study with almost 50 years of HA use actually got worse after training. Therefore, how long after fitting a HA can improvement be observed? This question cannot be answered from the present study because there was such a wide range of duration of HA use among participants. The extent to which experienced users can obtain benefit remains unknown. However, there may be an optimal training window during which it is ideal to recommend that HA users engage in a training program such as LACE™.

In addition, the hearing level may affect outcomes from training. Is the training of benefit only to those with moderate losses? Is there an upper limit of hearing loss, beyond which no benefit is likely? Preliminary observations from this study suggest that persons with mild to moderate losses obtained impressive gains. In contrast, the two persons with the greatest hearing loss did not. A better understanding of how hearing loss affects benefit from training would provide additional clinical significance.

### *Home Training*

The importance of encouraging clients to formally practice listening skills seems to be validated with this research since participants in both groups improved. Given the realities of access to healthcare, alternative interventions are desperately needed. Most adults seeking amplification are probably unaware that auditory training is even possible. For people who are aware of auditory training, access to traditional one-on-one therapy is limited. One participant who asked his audiologist about training options and was told that there were not any available. By not encouraging clients to complete a training program, we may unintentionally communicate that the HA will solve all their communication needs. While audiologists know that this is not the case, our lack of willingness to consider training may suggest otherwise. As audiologists, we should heed the suggestion made by one experienced HA user in this study who commented, “I

wished I had the opportunity to have a training program like this when I first got HAs.” This experienced HA user readily recognized the potential benefit. Why can’t we?

While the benefits from a home based auditory training program observed in this study are not conclusive, they are promising. Training in the home environment is consistent with an important component in the *International Classification of Functioning, Disability and Health* (ICF) framework. The ICF is rooted in a bio-psychosocial theory which posits that several areas contribute to an individual’s level of health and wellness (Hickson & Scarinci, 2007). Furthermore, the ICF recommends that additional personal and environmental factors may affect outcomes. Thus, LACE™ training indirectly may affect the communication environment at home. As was observed in this study, several individuals commented that by training at home, their spouses now had a better understanding of how difficult it was for them to understand conversations. This increased awareness about communication difficulties by significant others may be an indirect benefit of home training. By training at home, the environment in which communication takes place could be affected as well as the individual themselves. Ultimately, effective communication in real world settings, such as the home environment, is one target of our rehabilitative efforts. As such, the opportunity to train at home provides a mechanism through which individuals can actively participate in the rehabilitation process beyond using amplification.

## Appendices

### Appendix A Recruitment Flyer

# Volunteers Needed for a Home Auditory Training Study

Researchers at the University of Kentucky, College of Health Sciences are conducting a research study to measure the benefit of an auditory training program that can be used at home with your television to help improve listening for adults with hearing aids. Since some HA users are not satisfied with their current hearing aids, this training may be a useful way to help improve how well they understand speech in noise. Initial and follow-up testing occurs over 4 visits (about 1- 2 hours each) and training at home will occur over 4 weeks, but can be done at your convenience.

You may be able to participate if you:

Are an adult with hearing loss who is a new or experienced HA user

Are between 50-80 years of age

Have adequate vision to see and operate a television and remote control

Have no history of neurological or psychiatric disorder

If you meet these qualifications for the study, please contact Anne Olson, investigator and research coordinator, at (859) 218-0572 or [aolso2@uky.edu](mailto:aolso2@uky.edu).



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## Appendix B

### Informed Consent

#### Consent to Participate in a Research Study

#### **An Auditory Training Home Program for Adults with Hearing Aids**

##### WHY AM I BEING ASKED TO TAKE PART IN THIS RESEARCH?

You are being invited to take part in a research study about a DVD listening program that you can use at home with your own television to practice listening to speech. You are being invited to take part in this research study because you have hearing aids. If you agree to take part in this study, you will be one of about 36 people to do so at the University of Kentucky.

##### WHO IS DOING THE STUDY?

The person in charge of this study is Anne Olson, an audiologist in the Division of Communication Sciences and Disorders at the University of Kentucky, She is being supervised in this research by Jennifer Shinn, PhD. There may be other people on the research team assisting at different times during the study.

##### WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of this study is to measure the benefits of using a DVD listening program for adults who use hearing aids. By doing this study, we hope to learn if adult hearing aid users benefit from using this home listening program. We would also like to know if new hearing aid users get the same amount of benefit as experienced hearing aid users.

##### ARE THERE REASONS WHY YOU SHOULD NOT TAKE PART IN THIS STUDY?

You should not participate in this study if you are unable to speak English, because the auditory home training program is available only in English at this time. You should not participate in this study if you think you will not be able to complete the listening activities assigned each day. These activities may take about 30 minutes each day to complete. You should not participate in this study if you are receiving any other listening therapy at the same time.

##### WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

Four testing sessions will be conducted at the UK Communication Disorders Clinic. You will need to come to room 110A in the Charles T. Wethington Building. One session will occur before training, one session half way through training, one session after training ends and a final session 3 months after you complete the training. Each of those visits



will take about 1 -2 hours to complete. In between those testing sessions, you will also be completing a training program at home for 5 days per week for 4 weeks. Each of these training sessions will take about 30 minutes each day to complete. The total amount of time that you will be asked to volunteer for this study includes about 5-6 hours of testing and about 10 hours of training which may be completed at home over a 4 week period. Some individuals will be asked to return 3 months after they complete the training for a follow-up evaluation session which will take about 1 hour to complete.

## WHAT WILL YOU BE ASKED TO DO?

**Testing** All of the tests you will be asked to complete have been used before and are considered routine. None of the procedures are experimental. Before training, you will be asked to answer some questions about how you feel about your hearing loss and your ability to communicate with other people especially in difficult listening conditions. You will also complete a computer reading task where you will read sentences on a screen and also try to recall individual letters. You will also complete routine speech understanding tests where you will repeat words and sentences that will tell us how well you understand speech. These tests will be similar to hearing tests you have probably had in the past.

**Before Training:** One of the research helpers will teach you how to run the DVD player through your home television after baseline testing is finished. Every step that you need to do to run the television and remote control will be described to you. We will also provide written step by step directions and give you our phone number so you can call us if there is a problem. We will practice with you to make sure you understand how the training program works. For this study, the DVD needs to be played through a DVD player and viewed on a television. Since all of the training is done through a DVD player, if you do not have a DVD player in your home, then we will loan you one so that you can complete the training. If you have any problems setting up your DVD player, you may call Anne Olson at 859-518-0572, Monday through Friday from 9:00am -5:00pm. There will be 3 different groups in this study. Group 1 will be persons who have just received their hearing aids (with at least 4 weeks of use) and will also complete the DVD training. Group 2 will be persons who have had their hearing aids for at least 2 years and will also complete the training. Group 3 will be persons who have just received their hearing aids (with at least 4 weeks of use) and will receive no additional training during the study period. Group 3 persons will have the opportunity to use and keep the training program after the end of the study. Persons who are new hearing aid users will be randomly assigned to either Group 1 or Group 3. If you are assigned to Group 1 you will receive the training immediately whereas if you are assigned to Group 3 you will have the choice to complete the training after a 4 week period. Once you agree to participate, please make every effort to complete the training sessions.

**Training:** You will use your hearing aids at their regular setting before you begin training. You will be listening to different words and sentences through your television. There will also be background noise coming from the television, so it may sound like you're listening in a cafeteria. These sentences are between 4-7 words long. Each time you hear a sentence, you will be asked to repeat it to yourself. After you have repeated it to

yourself, the television will prompt you to press a button on your remote control so that you can see the correct response on the television screen. If your answer matches the DVD screen answer, then the program will score this as correct. If your answer was incorrect, the program will score this as incorrect and you will be able to listen to this stimulus again. You will continue to listen to many sentences and respond to the prompts from the television after each sentence until that set is finished.

Below is a table that shows the schedule of activities that you would complete if you chose to participate in this study.

Table 1. Schedule of Activities for Participants

<b><u>Baseline Visit</u></b> Baseline Assessment (90 min) DVD orientation (30 min)	<b><u>Tx Phase</u></b> Training at home (10 lessons for 2- weeks)	<b><u>Second Visit</u></b> (60 min) 2 wk assessment	<b><u>Tx Phase</u></b> Training at home (10 lessons for 2-weeks)	<b><u>Post Therapy Visit</u></b> ( 1 hour) 4-wk assessment
1. Informed Consent				
2. Background Information Degree of HL, duration, etiology, age, etc.				
3. Reading Span Test (Cognitive Predictor Variable)				
4. Hearing Aid Verification (Verifit)		Verifit		Verifit
5. Sentence Recognition: Quick SIN (Speech in Noise)		Quick SIN		Quick SIN
6. Compressed Speech		Compressed Speech		Compressed Speech
7. Synthetic Sentence Identification (SSI)		SSI		SSI
8. Speech, Spatial and Qualities of				SSQ

Hearing Scale (SSQ)				
				International Outcomes Inventory (IOI)

**WHAT ARE THE POSSIBLE RISKS and DISCOMFORTS?**

There are minimal risks for individuals who participate in this study. The potential discomfort of participating in this study is that you may become more aware of what you do and do not understand especially after finishing the word and speech understanding tests. Some people may be discouraged about how they did on these tests, but the main purpose of these pre-training tests is that they will help the researchers measure how much benefit you receive from the training.

**WILL YOU BENEFIT FROM TAKING PART IN THIS STUDY?**

There are possible benefits for individuals who participate in this study. Many people who have completed similar training programs understood speech better than those who did not complete a training program. However, there is no guarantee that you will get any benefit from taking part in this study. However, some people have experienced improved speech understanding following this type of training. Your willingness to take part, however, may, in the future, help hearing professionals better understand and/or treat others who have hearing loss and are hearing aid users.

**DO YOU HAVE TO TAKE PART IN THE STUDY?**

If you decide to take part in the study, it should be because you really want to volunteer. You do not have to participate if you chose not to volunteer. You can stop at any time during the study. If you decide not to take part in this study, your decision will have no effect on the quality of hearing services you receive.

**IF YOU DON'T WANT TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?**

If you do not want to be in the study there are no other choices except not to take part in the study.

**WHAT WILL IT COST YOU TO PARTICIPATE?**

You may incur small financial costs related to missed time at work in order to complete the baseline and post therapy testing. Therefore every effort will be made to conduct these tests when it is most convenient for you. All parking vouchers will be stamped so that you do not need to pay for parking. Finally, since all training will be done at home, you will be able to complete this activity at a time when you choose.

**WHO WILL SEE THE INFORMATION THAT YOU GIVE?**

We will keep private all research records that identify you to the extent allowed by law. Reports including your responses to questionnaires, background information, and any hearing or any other test results will be kept private. We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. All documents will be tracked by a combination of first and last initial and research number to protect participant's privacy and will be stored in a locked cabinet in the communication disorders department. Your information will be combined with information from other people taking part in the study. The results from the study will be shared with other hearing researchers at the end of the study. When we write about the results, we will write about the combined information we have gathered. You will not be personally identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private. Officials from the University of Kentucky may look at or copy pertinent portions of records that identify you.

#### CAN YOUR TAKING PART IN THE STUDY END EARLY?

If you decide to take part in the study you still have the right to decide at any time that you no longer want to continue. You will not be treated differently if you decide to stop taking part in the study. The individuals conducting the study may need to withdraw you from the study if you are unable to follow directions or repeat the tasks.

#### ARE YOU PARTICIPATING OR CAN YOU PARTICIPATE IN ANOTHER RESEARCH STUDY AT THE SAME TIME AS PARTICIPATING IN THIS ONE?

You may not take part in this study if you are currently involved in another research study that is also related to your hearing loss. It is important to let the investigator know if you are in another research study. You should also discuss with the investigator before you agree to participate in another research study while you are enrolled in this study.

#### WHAT HAPPENS IF YOU GET HURT OR SICK DURING THE STUDY?

If you get hurt or sick during this study and are unable to finish the training sessions, please call Anne Olson at 859-323-1100 x 80572 as soon as possible. It is important for you to understand that the University of Kentucky does not have funds set aside to pay for the cost of any care or treatment that might be necessary because you get hurt or sick while taking part in this study. Also, the University of Kentucky will not pay for any wages you may lose if you are harmed by this study.

#### WILL YOU RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?

Participants who complete the training will receive a monetary reward the end of the training. You will also receive the DVD for free and will be able to keep this training program for future personal use. Persons in the control group will also receive the DVD

program for free at the end of the study for their own future personal use. Parking fees associated with follow-up assessments will be paid by the investigator.

**WHAT IF YOU HAVE QUESTIONS, SUGGESTIONS, CONCERNS, OR COMPLAINTS?**

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions, suggestions, concerns, or complaints about the study, you can contact the investigator, Anne Olson at 859-323-1100 x 80572. If you have any questions about your rights as a volunteer in this research, contact the staff in the Office of Research Integrity at the University of Kentucky at 859-257-9428 or toll free at 1-866-400-9428. We will give you a signed copy of this consent form to take with you.

**WHAT IF NEW INFORMATION IS LEARNED DURING THE STUDY THAT MIGHT AFFECT YOUR DECISION TO PARTICIPATE?**

If the researcher learns of new information in regards to this study, and it might change your willingness to stay in this study, the information will be provided to you. You may be asked to sign a new informed consent form if the information is provided to you after you have joined the study.

**WHAT ELSE DO YOU NEED TO KNOW?**

It is important for you to know that you do not give up your legal rights by signing this form. The researcher is conducting this research in part to fulfill her requirements for completion of a doctoral degree in Rehabilitation Sciences. The investigator has no financial interest in the use or development of the training program.

\_\_\_\_\_  
Signature of person agreeing to take part in the study

\_\_\_\_\_  
Date

\_\_\_\_\_  
Printed name of person agreeing to take part in the study

\_\_\_\_\_  
Name of [authorized] person obtaining informed consent  
Anne D. Olson - Investigator  
Jennifer B. Shinn - Co-Investigator

\_\_\_\_\_  
Date

\_\_\_\_\_  
Signature of person obtaining informed consent

## Appendix C

### Loudness Judgment Chart

- 7. Uncomfortably Loud**
- 6. Loud, but OK**
- 5. Comfortable, but slightly loud**
- 4. Comfortable**
- 3. Comfortable, but slightly soft**
- 2. Soft**
- 1. Very Soft**

## Appendix D

### The International Outcomes Inventory (IOI)

#### The International Outcomes Inventory– Alternative Interventions (IOI-AI)

(Noble, 2002)

1. Think about how much you used your hearing aids over the past 2-weeks since the LACE™ training. On an average day, how many hours did you use them ? [Use]  
None   less than 1 hr/day   1-4 hr/day   4-8 hr/day   more than 8hr/day
2. Think about the situation where you most wanted to hear better, before doing the LACE™ training. Over the past 2-weeks, how much has the LACE™ training helped in that situation ?[Benefit]  
Helped not at all   Helped slightly   Helped moderately   Helped quite a lot  
Helped very much
3. Think again about the situation where you most wanted to hear better before doing the LACE™ training. Since the training, how much difficulty do you STILL have in that situation? [Residual Activity Limitations]  
Very much difficulty   Quite a lot of difficulty   Moderate difficulty  
Slight difficulty   No difficulty
4. Considering everything, do you think that doing the LACE™ training was worth the trouble? [Satisfaction]  
Not at all worth it   Slightly worth it   Moderately worth it  
Quite a lot worth it   Very much worth it
5. Over the past 2-weeks, since completing the LACE™ training, how much have your hearing difficulties affected the things you can do? [Residual Participation Restrictions]  
Affected very much   Affected quite a lot   Affected moderately  
Affected slightly   Affected not at all
6. Over the past 2-weeks since completing the LACE™ training, how much were other people bothered by your hearing difficulties ? [Impact on Others]  
Bothered very much   Bothered quite a lot   Bothered moderately  
Bothered slightly   Bothered not at all

7. Considering everything, how much has using the LACE™ training changed your enjoyment of life? [Quality of Life]

- Worse
- No change
- Slightly better
- Quite a lot better
  
- Very much better

Adherence

Did you complete all of the training sessions?

- Yes
- No

If you answered No to the previous question, how many of the 20 sessions did you complete? \_\_\_\_\_

If you did not complete all of the training sessions, why were you unable to complete them?

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Do you have any positive or negative comments to share about the LACE™ training program?

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Appendix D (continued)

The International Outcomes Inventory – Hearing Aid (IOI-HA)

(Cox & Alexander, 2002)

1. Think about how much you used your present hearing aids over the past 2-weeks. On an average day, how many hours did you use them ? [Use]  
None   less than 1 hr/day   1-4 hr/day   4-8 hr/day   more than 8hr/day
2. Think about the situation where you most wanted to hear better, before you got your present hearing aids. Over the past 2-weeks, how much have the hearing aids helped in that situation?[Benefit]  
Helped not at all   Helped slightly   Helped moderately   Helped quite a lot  
Helped very much
3. Think again about the situation where you most wanted to hear better . When you use your present hearing aids how much difficulty do you STILL have in that situation? [Residual Activity Limitations]  
Very much difficulty   Quite a lot of difficulty   Moderate difficulty  
Slight difficulty   No difficulty
4. Considering everything, do you think your present hearing aids are the trouble? [Satisfaction]  
Not at all worth it   Slightly worth it   Moderately worth it  
Quite a lot worth it   Very much worth it
5. Over the past 2-weeks, with your present hearing aids, how much have your hearing difficulties affected the things you can do? [Residual Participation Restrictions]  
Affected very much   Affected quite a lot   Affected moderately  
Affected slightly   Affected not at all
6. Over the past 2-weeks with your present hearing aids, how much were other people bothered by your hearing difficulties ? [Impact on Others]  
Bothered very much   Bothered quite a lot   Bothered moderately  
Bothered slightly   Bothered not at all
7. Considering everything, how much has your present hearing aids changed your enjoyment of life ? [Quality of Life]

Worse No change Slightly better Quite a lot better Very much better

Appendix E

Schedules of activities for participants in training and control groups

Activities for participants in training groups

<b><u>Baseline Visit</u></b> (Total: 2 hours)	<b><u>Training</u></b> <b><u>at home</u></b> 2-weeks	<b><u>2-week</u></b> <b><u>follow-up</u></b> (1 hour)	<b><u>Training</u></b> <b><u>at home</u></b> 2-weeks	<b><u>4-week</u></b> <b><u>follow-up</u></b> (1 hour)
1. Informed Consent				
2. Background Information				
3. Reading Span Test				
4. Pure tone hearing test				Hearing test
5. HA Verification (Verifit)		Verifit		Verifit
6. Quick Speech in Noise (Quick SIN )		Quick SIN		Quick SIN
7. Compressed Speech		Compressed Speech		Compressed Speech
8. Synthetic Sentence Identification (SSI)		SSI		SSI
9. Speech, Spatial and Qualities of Hearing (SSQ)				SSQ
10. DVD Training				
				11.Int'l Outcome Inventory – (IOI- AI)

Appendix E (continued)

Schedules of activities for participants in training and control groups

Activities for participants in control group

<b><u>Baseline Visit</u></b> (Total: 2 hours)	<b><u>No</u></b> <b><u>Training</u></b>	<b><u>4-week follow-up</u></b> (Total: 1 hour)
1. Informed Consent		
2. Background Information		
3. Reading Span Test (Working Memory)		
4. Hearing Test		Hearing test
5. HA Verification (Verifit)		HA Verification (Verifit)
6. Quick Speech in Noise (Quick SIN )		Quick SIN
7. Compressed Speech		Compressed Speech
8. Synthetic Sentence Identification (SSI)		SSI
9. Speech, Spatial and Qualities of Hearing Scale (SSQ)		SSQ
		10. Int'l Outcome Inventory – Hearing Aid (IOI-HA form )
		11.DVD Training

## Appendix F

### Background Information

Subject research number (group, #, initials, gender)  
Consent & HIPPA (date) Interview Date  
Date of Birth Age Gender  
Best Phone Contact email  
Education Level in Years (circle one)  
12 = HS 16= Bach 18= Master's >22= PhD or MD  
Race (Circle one or more)  
Asian Hispanic African American White Pacific Islander  
Alaskan Native American Indian  
Age HL Identified  
Type of Hearing Aid: RE: LE:  
HA Fit Date: Length of HA Use:  
Do you own a television? Yes No  
Do you own a DVD? Yes No  
Has a doctor ever told you that you've had a stroke or other neurologic event?  
Yes No  
Has a doctor ever told you the cause of your hearing loss?  
Yes No  
If yes, then what is the cause of your hearing loss?  
Do you see well enough to see and operate your television  
Yes No  
Do you see well enough to see and operate the remote control ?  
Yes No  
Please rate your overall health:  
Very Good Good Fair Poor Very Poor

## Appendix G

### Step by step by step directions for playing LACE™ DVD

1. Open the DVD container and take out the green DVD.
2. Turn on the DVD player if it is not already on.
3. Turn on the TV if it is not already on.
4. Push the eject button to open the DVD holder. (Triangle over a rectangle)
5. Put the DVD in the holder.
6. Push the eject button again to make the DVD go into the DVD player.
7. Push the play button
8. A screen will come up that has Begin LACE™ Training, press the play button again.
9. A question will come up asking whether this is the first day with LACE-DVD Training. To click yes, press play again. To click no, use the remote to move the cursor over. Push the triangle pointing to the left, which is the left arrow.
10. The DVD has step by step instructions from this point.
11. At the end of the training session a score will appear on the television screen. Enter this score on the yellow score card that corresponds to the day of training.

## Appendix H

### Instruction Sheet for LACE™ Training

#### General Description of LACE™ training

You will use your hearing aids at their regular setting before you begin training. You will be listening to different sentences through your television. There will also be background noise coming from the television, so it may sound like you're listening in a cafeteria. These sentences are between 4-7 words long. Each time you hear a sentence, you will be asked to repeat it to yourself. After you have repeated it to yourself, the television will prompt you to press a button on your remote control so that you can see the correct response on the television screen. If your answer matches the DVD screen answer, then the program will score this as correct. If your answer was incorrect, the program will score this as incorrect and you will be able to listen to this stimulus again. You will continue to listen to many sentences and respond to the prompts from the television after each sentence until that set is finished.

#### General Room set-up

1. It's important to conduct the training under similar conditions each day, so try to choose a quiet time of day, a quiet location for the training and when you're not too tired.
2. It's also important to position yourself in the same place each day for the training. To do this, you need to mark a spot –3 feet from the television --where you will place a chair each day so that you can complete the training.
3. It's also important to conduct the training at the same volume levels each day. Therefore, first make sure that your hearing aids are on and are set to their "regular use" settings before you begin the training. Secondly, during the LACE set-up each day, you will be instructed to adjust the level of the volume with the remote control. After doing this do not change the volume level for the remainder of the training.

**Please call Anne Olson, Monday –Friday at 859-323-1100 x 80572 if you have any questions about your DVD set-up or room set-up once you get home.**

Appendix I

Scorecard to report daily scores after LACE™ training

**LACE DVD Scorecard**

Day:	1	2	3	4	5
Speech In Noise					
Rapid Speech					
Competing Speaker					

Day:	6	7	8	9	10
Speech In Noise					
Rapid Speech					
Competing Speaker					



## Appendix J

### Worksheet for procedural reliability

Subject Number \_\_\_\_\_

Date \_\_\_\_\_

Group (circle one) New + Training    Exp + Training    New – Control

Item	Discussed	Not Discussed
1. Provide general description of LACE™DVD training program		
<b>Room Set up</b>		
2. Discuss when to train ( quiet time of day and not too tired)		
3. Position for training. To do this, you need to mark a spot –3 feet from the television --where you will place a chair each day		
4. Volume level of training – Hearing aid settings – once selected, do not change this		
5. Volume level of training – TV Settings - once you select volume level, do not change this during the training.		
<b>LACE™ DVD Training</b>		
6. Open the DVD container and take out the DVD that has DVD Video on it.		
7. Turn on the TV if it is not already on.		
8. Turn on the DVD player if it is not already on.		
9. Insert DVD into DVD player		
10. Push the play button		
11. A screen will come up that has Begin LACE Training, press the play button again.		
12. A question will come up asking whether this is the first day with LACE-DVD Training. To click yes, press play again. To click no, use the remote to move the cursor over. Push the triangle pointing to the left, which is the left arrow.		
13. Follow the DVD's step by step instructions from this point.		
14. At the end of the training session a score will appear on the television screen. Enter this score on the yellow score card that corresponds to the day of training.		
Tally number of items discussed and not discussed		
% Agreement = total discussed – total not discussed / total number of items		

## Appendix K

### Worksheet for inter-scorer reliability

#### Inter-Scorer Reliability Quick SIN (live)

Subject Number \_\_\_\_\_

List Number	Rater 1	Rater 2	# of agreements
1 (total correct)			
2			
3			
4			
5			
6			
Total # Agreement			
Total # Possible Agreement			
% agreement (# agree/total poss agree)			

#### Inter-Rater Reliability Compressed Speech (live)

Subject Number \_\_\_\_\_

List Number	Rater 1	Rater 2	# of agreements
Total Correct			
Total # Agreement			
Total # possible agreement			
% agreement (# agree/total poss agree)			

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## Vita

Anne D. Olson

### GENERAL INFORMATION

Date of Birth: August 4, 1960  
Place of Birth: Hartford, CT

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College of Health Sciences  
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### CERTIFICATION/LICENSURE

Certificate of Clinical Competence – Audiology -1986-Present, American Speech-Language-Hearing Association. Rockville, MD.

Licensed Audiologist - 1990- Present, Kentucky Board of Speech-Language Pathology and Audiology. Frankfort, KY. License # 203

Licensed Hearing Aid Dispenser – 1991 – 2007, Kentucky Board of Hearing Instrument Dispensers. Frankfort, KY . License #606.

### EDUCATION

Institution	Location	Dates	Major	Degree
University of Kentucky	Lexington, KY	Aug 2004	Rehabilitation Sciences	
University of Texas	Austin, TX	Aug. 1982- Dec., 1985	Audiology	M.A.
University of Florida	Gainesville, FL	Aug., 1978- Dec., 1981	Speech.	B.A.

### PROFESSIONAL EXPERIENCES

<u>Dates</u>	<u>Title</u>	<u>Institution</u>
August 2004 – Present	Assistant Professor	University of Kentucky



<u>Dates</u>	<u>Title</u>	<u>Institution</u>
September 2000- June 2004	Educational Audiologist	Fayette County Public Schools
April 1990-June 2003	Clinical Audiologist	Lexington Hearing & Speech Center Lexington, KY
April 1990- June 1993	Clinical Audiologist	Central Kentucky ENT Lexington, KY
April 1987- October 1989	Clinical Audiologist	Randolph Road ENT Charlotte, NC
September 1984- September 1986	Clinical Audiologist	Austin Ear Clinic Austin, TX

### **ACADEMIC APPOINTMENTS**

2004 – Present          Full-Time, Special Title Series, Assistant Professor,  
Division of Communication Disorders, College of Health Sciences, University of  
Kentucky, Lexington, KY

### **CONSULTING ACTIVITY**

2000                  Cochlear implant in educational settings (February), Jessamine County  
Cochlear implant in educational settings, (February), Harlan County  
Cochlear implant in educational settings, ( June), Carter County  
Cochlear implant in educational settings, (March), Whitley County  
1995                  Cochlear implant in educational settings, (January), Knox County

### **TEACHING ACTIVITY**

University of Kentucky, Lexington, KY  
Audiology (UG-3 cr)  
Aural Rehabilitation (G/UG- 3cr)  
Independent Study in Aural Rehabilitation (G- 3 cr)  
Clinical Management of Communication Disorders (UG-3 cr)  
Clinical Rotation in Speech Language Pathology (G -3 cr)  
Speech and Hearing Science (UG-3 cr)  
Communication Options in Deaf and Hard of Hearing (G-1cr)  
Guest Lectures – College of Medicine, College of Education, College of Health Sciences

## **ADVISING ACTIVITY**

University of Kentucky, Division of Communication Disorders

Master's Thesis Committees:

Member: Heather Gaddis (completed, May 2006)

Member: Anne Latin (completed, May 2009)

Member: Tracy Watts

Advising

Graduate and Undergraduate Academic Advising (6 G; 9 UG)

## **ADMINISTRATIVE ACTIVITY & UNIVERSITY SERVICE**

A. University

B. Department/Division

2006, 2008, 2009, 2010

Member, Undergraduate Writing Committee

2004 - present CD Teacher Education Program Faculty

2004 – present UG and Graduate Admissions Committee

C. College

2009- present Faculty Council

2008-2010 Student Affairs Committee

2007-present Spanish Health Fair (College of Medicine)

## **HONORS**

Student scholarship, *Audiology Research Travel Award*. American Speech, Language and Hearing Association Annual Convention. New Orleans, LA, November, 2009.

Student scholarship, *Summer Institute on Communication Sciences and Disorders*, University of Iowa, Iowa City, Iowa. Sponsored by Council of Academic Programs in Communication Sciences and Disorders and the American Speech, Language and Hearing Association. June-July 2007.

Student scholarship, *State of the Science Conference on Hearing Enhancement*, Gallaudet University, Washington, DC, September 2006.

Honors of the Association, Kentucky Speech-Language-Hearing Association Annual Conference, February, 2005.

## Professional Activity & Public Service

### A. Memberships

2006-present	Member, American Academy Rehabilitative Audiology
2006-present	Member, American Auditory Society
2000-2007	Member, Educational Academy of Audiology
2000-present	Member, American Academy of Audiology
1990-present	Member, Kentucky Speech-Language and Hearing Association
1985-present	Member, American Speech-Language and Hearing Association
1987-1989	Member, North Carolina Speech-Language and Hearing Association
1985-1986	Member, Texas Speech-Language and Hearing Association

### B. Public Service Activities

2006-present	Facilitator Adult Cochlear Implant Support Group
2005-present	Hearing Screenings at Health Fairs (Clays Mill Elementary School, Ballard and Griffen Towers, UK Spanish Health Fair)
2005-present	Hearing Information and Hearing Aid Sessions (Lexington Senior Citizen Center, Ashland Terrace, Central Christian Towers)
2005	Coordinator for student volunteers at Fayette County Public Schools D/HH Spring Social
2001	Saigon Children's Charity – Ho Chi Minh City, Vietnam
1992-1994	Central Kentucky Hearing Aid Bank – Volunteer

### C. Professional Service/ Committees

2009-present	Member, Kentucky Speech Language Pathology and Audiology Licensure Board
2008	Member, Learning Lab Program Planning Committee, American Academy of Audiology.
2006	Reviewer, Proposals for American Academy of Rehabilitative Audiology, September 2006, Louisville, KY.
2005	CFY Supervisor, Angela Bonino, audiologist
2003-2005	Member, Kentucky HEARS program
1993-1996	Member, Kentucky Telephone Relay Service Committee

### SPEAKING ENGAGEMENTS:

#### State/Regional

Harrison, A., Olson, A. (2010). Linking age related sensory loss and function outcomes. Baptist Hospital East. January 30. Louisville, KY.

Harrison, A., Olson, A. (2009). Linking age related sensory loss and function outcomes. Cardinal Hill. October 20. Lexington, KY.

Olson, A. (2007). Hearing loss in school settings. Asbury College. March 26. Wilmore, KY.

Olson, A. (2006). Evidence Based Practice: A Systematic Review of the Evidence for Bimodal Stimulation. University of Louisville Audiology Meeting, June 19, Louisville, KY.

Olson, A. (2004). Hearing impaired students in the regular classroom. Kentucky School for the Deaf Regional Outreach Program, September 15, Bowling Green, KY.

Olson, A. (2004). Cochlear implants in the preschool setting. Kentucky School for the Deaf, Early Childhood and Family Education Services, March 11, Danville, KY.

Olson, A. (2003) Auditory processing assessments and interventions. Ohio Valley Educational Co-Operative. December 5, Shelbyville, KY.

Olson, A. (2003). Cochlear implants in the educational setting. Heuser Hearing Institute, July, Louisville, KY.

Olson, A. (2002). Current hearing aid technologies. Vocational Rehabilitation – Department for the Blind, May, Frankfort, KY.

Olson, A. (2002). Cochlear implant overview. Kentucky School for the Deaf, April, Danville, KY.

Olson, A. (1999). Amplification for infants and children. Kentucky Early Years, September 1999, Prestonsburg, KY

Olson, A. (1998). Current hearing aid technologies. Vocational Rehabilitation – Department for the Blind, May 1998 Frankfort, KY.

Mitchell, T., & Olson, A. (1996). Cochlear implant update. Kentucky Commission for the Deaf and Hard of Hearing, October 1996, Frankfort, KY.

Ragsdale, E., Rutledge, S., & Olson, A. Hearing loss and early identification. Family Learning Vacation, Kentucky School for the Deaf, June 1996, Danville, KY.

## **RESEARCH PRODUCTIVITY**

### **A. Refereed Presentations**

#### **State**

Donaldson, C., Eisenmenger, B., and Olson, A. (2000). Cochlear implants in Kentucky. Kentucky Conference on Communication Disorders, March 8-11, Louisville, KY.

Hustedde, C and Olson, A. (1993). Communication Accessibility and the ADA. Kentucky Conference on Communication Disorder, March, Lexington, KY

#### National

Olson, A., & Shinn, J. (2007). A systematic review of the effectiveness of bimodal stimulation. (Poster). Annual American Auditory Society. March 4-6, Scottsdale, AZ.

Olson, A., & Huebner, R. (2005). Life course concepts and counseling deaf adults seeking implantation.(Poster) Annual Convention of the American Speech-Language and Hearing Association. November 17-20, San Diego, CA.

#### Publications

#### Manuscripts

Desmarais, A. (1985). Adaptive two-interval forced choice loudness matching procedures with hearing impaired listeners. Masters Thesis. University of Texas, Austin, Texas.

#### Journal Articles

Olson, A. D. (2006, Sept). Counseling adults prior to a cochlear implant: Those with prelingual or long-term hearing loss benefit from a team approach. *The ASHA Leader*, 11(13), 18-19.

Olson, A.D., Shinn, J. (2008). A systematic review of the effectiveness of using amplification in conjunction with cochlear implantation. *Journal of the American Academy of Audiology*, 19, 657-671.

Olson, A.D., Pugh, B., & Bishop, M (2009). Rehabilitation counselors' knowledge of cochlear implants. *Journal of Applied Rehabilitation Counseling*, 40 (1), 27-34.

#### Book Chapter

Harrison, A.L., Olson,A.D., Shaffer, S.(submitted, anticipated published date 2010). Aging and sensory loss: Somatosensory, vestibular, vision and hearing. In *Case-based geriatrics: A global approach*. Eds. Hirth, V., Wieland, D., McGraw Hill.

#### Grant Activity:

Approved and Funded – Intramural

2006-2007 Vocational rehabilitation counselors' knowledge about cochlear implants.  
Institute for Educational Research (College of Education) University of Kentucky.  
Bishop, M (PI) Olson, A (Co PI) & Pugh, B (Co-PI), \$4,251.00.