Examining the Effects of LACE Training on Cognitive Function in Older Adults: An ERP Study

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Aging is known to bring changes and decline to the human brain and body, especially in hearing. Cognition can decline with age alone, but can be accelerated when hearing is impaired. Cognitive decline can affect older adults' everyday lives, particularly when it comes to driving. Driving cessation is also associated with mental depression, which can lead to heart disease or other serious health conditions. However, there are cognitive training programs that are designed to promote brain plasticity and create new neural pathways. Event Related Potentials (ERPs) can be used to show the neurophysiological changes in cognition that follow such training. The P3a is associated with involuntary attention as well as inhibition. In this study, a well-developed cognitive training program, Listening and Communication Enhancement (LACE), is used to see if older adults can slow or reverse age-related cognitive decline. Participants (*n*=18) were tested during three sessions (baseline, pre-training, and post-training) using an attentional blink (AB) paradigm. The AB task was measured with a short stimulus onset asynchrony (SOA) and a long SOA. Training occurred during the pre-training session but after participants had been tested, then again during the post-training. Electroencephalography (EEG) recordings were taken at each session during AB testing. Results showed that participants' P3a mean amplitude for short SOA decreased across sessions, specifically after training had occurred. P3 mean amplitude for long SOA did not significantly change at all. This would suggest that training helped older adults reverse the age-related cognitive decline.

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Aging and Auditory Deterioration

Aging is associated with changes and impairments that occur throughout the body. Research has shown that declines in sensory, cognitive, and socio-emotional processes occur as we age (Craik & Salthouse, 2011; Gordon-Salant, Frisina, Popper, & Fay, 2010; Tun, Williams, Small, & Hafter, 2012). In hearing, many of these initial declines occur in the physical components of the ear. Deterioration of the inner ear can make detrimental differences to hearing (Chisholm, Willot, & Lister, 2003; Schneider & Pichora-Fuller, 2000). Middle and inner ear connective joints can develop arthritis, which in turn can cause blood vessels to decrease in size. This can ultimately limit blood flow and damage the cochlea, which turns sound energy into electrical neural energy that can be processed by the brain. When the processing power of the cochlea is slowed, this can again result in hearing loss (Tun et al., 2012). As people age, the cochlea, as well as other areas (commonly hair cells and ganglion cells), deteriorate. All of these declines have been correlated with hearing loss in older adults (Chisholm et al., 2003).

Neural connectivity and synchrony can deteriorate as a result of the physical deterioration of the inner and outer ear. Schneider and Pichora-Fuller (2000) discuss evidence for hearing loss beyond the physical deterioration of the ear. When damage to the ear occurs, or certain neural pathways are not used, they deteriorate. If the nerve cells are not activated on a regular basis, they become obsolete and die (Anderson & Kraus, 2010; Schneider & Pichora-Fuller, 2000). Neural degradation commonly occurs from damage and deterioration of hair cells in the inner ear

(Chisholm et al., 2003). Damage to hair cells can be a result of various loud noises over the span of a person’s lifetime (i.e. loud concerts, plane engines, sirens, etc.). However, neural degradation in the auditory cortex can also occur naturally with age (Schneider & Pichora-Fuller, 2000). Damage to hair cells, combined with the natural deterioration associated with aging, makes it difficult for older adults to hear high and low pitches in sound and speech. This leads to the neural degeneration in the auditory cortex. Neural degeneration in the auditory cortex is usually complete, meaning the entire neuron (soma, axon, and dendrites) dies (Chisholm et al., 2003).

It is difficult to identify when people have neural degeneration problems associated with hearing, but a common sign is the difficulty to understand words in speech. Tremblay, Piskosz, and Souza (2003) investigated how older adults with hearing problems varied from young and older adults with normal hearing in speech perception. Participants were given sets of voice-onset-time trials (VOT), where different frequencies of word sounds were presented and measured based on time recognition. The researchers found that older adults (with and without hearing loss) took more time to process the words and to give a response to the VOT task (Tremblay et al., 2003). Furthermore, older adults with hearing loss performed significantly worse on the VOT task than older adults without hearing loss. These results suggest that hearing loss affects auditory processing time in older adults. While deteriorating sensory processes may be a contributing factor to hearing loss, the understanding of language could be an even greater factor.

Cognitive Decline in Older Adults

The age at which cognitive decline begins has been debated (Aartsen, Smits, van Tilburg, Knipscheer, & Deeg, 2002; Albert & Moss, 1988; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005). Some research suggests that cognitive decline does not occur until the later ages of life (60s or 70s; Aartsen, et al., 2002). Other research reports that cognitive decline starts to occur around age 50 or slightly before (Albert & Moss, 1988; Rönnlund et al., 2005). However, research by Salthouse (2009) suggests that cognitive decline can start in the late 20's to early 30's. In order to measure this, Salthouse recruited participants from a wide range of ages (18 to 60). Each participant was given four standardized tests (WAIS III Vocabulary and Digit Symbol; WMS III Word Recall and Logical Memory) and were then asked to come back for a short-term (1 to 14 days) and long-term retest (1 to 7 years). Salthouse (2009) found that participants started showing signs of cognitive decline well before the age of 60, as early as the late 20s. However, there was a large amount of variability among participants and in the rate at which cognitive decline occurred.

Different theories exist as to why cognitive decline occurs. One idea states that older adults lack inhibition when filtering out input (e.g., sounds) from multiple sources (Gmehlin, Kresiel, Bachmann, Weisbrod, & Thomas, 2011; Tremblay et al., 2003). This idea stems from the theory known as the inhibitory deficit hypothesis (Connelly, Hasher, & Zacks, 1991). In their study, Connelly and colleagues had younger and older adults read text from a passage out loud. Among the text was a distractor in a different font. Older participants read the sentences significantly slower than the younger participants. Connelly et al. (1991) believe this suggests that older adults have difficulty blocking out the task-irrelevant visual information. In order to address auditory inhibition among visual attention, Alain and Woods (1999) measured younger and older adults (who had been screened and excluded for hearing loss) with one of two auditory tasks. The first task consisted of listening to a sequence of tones made up of small and large deviant tones throughout; participants were asked to identify which tone change they heard. The second task also consisted of a sequence of tones, but this time the tones alternated in frequency and repetition. Participants were tasked with ignoring the auditory stimuli while identifying changes in a set of visually presented black bars. Reaction time accuracy was measured by participants pressing a button on the keyboard. Oddly enough, reaction times were the same between younger and older adults. Alain and Woods (1999) believe this is due to the simplicity of the task performed in their study because in other studies the tasks have been more difficult. This would suggest that older adults may have difficulty inhibiting responses or have a different response criterion than young adults (Alain & Woods, 1999).

While the inhibitory deficit hypothesis is a well-known theory for its explanation of cognitive decline in older adults, it does not differentiate between sensory and cognitive decline very well. Another major theory that describes both sensory and cognitive decline in older adults is the frontal hypothesis of aging. Originally known as the hemispheric asymmetry reduction in older adults (HAROLD), this hypothesis states that the frontal cortex deteriorates in older adults, which causes problems with inhibition and other cognitive abilities (Andrés, Parmentier, & Escera, 2006; Cabeza, 2002). In the early studies on HAROLD, researchers found a bilateral change in the prefrontal cortex (PFC) that was associated with verbal recall in older adults. Since then, researchers have replicated this PFC change in different tasks (Cabeza, 2001; Cabeza et al., 1997). Cabeza (2002) then showed that the PFC change was due to aging and not specific to a task. Inhibitory deficits allow for irrelevant information to access working memory, which then clutters and impairs working memory. In association with the HAROLD model, this means that older adults need to use more resources from their PFC in order to perform at the same inhibitory level as younger adults (Cabeza, 2002). Andrés and colleagues (2006) tested the frontal hypothesis of aging by using visual stimuli and auditory distractors. Normal hearing participants were presented with a series of numbers and were asked to categorize them as odd or even, while concurrently presented with an irrelevant auditory distraction. Reaction times were measured in order to find differences between younger and older participants. Older adults' reaction times were much slower compared to younger adults when the distraction was played. The researchers also found that older adults' accuracy was slightly lower than that of younger adults when a novel sound was played. Andrés et al. (2006) believe this shows that more attentional resources are being used by older adults than younger adults. This suggests that older adults have difficulty inhibiting irrelevant sounds when working on a task, which in turn affects their cognitive performance. Andrés and colleagues believe this is due to the frontal cognitive decline associated with aging. In support of these findings, Persson et al. (2006) studied structural brain changes associated with longitudinal cognitive performance in normal aging younger and older adults using functional magnetic resonance imaging (fMRI). Participants were given a face recognition task. They were presented with 12 new and 12 previously presented faces and were asked to indicate if yes, they had seen the face before, or no, they had not seen the face. The second task was a free-recall of sentences, where imperative form sentences, such as "close the door" or "give me the keys," were displayed and participants had to remember as many as possible. Results showed that older adults had increased activity in the frontal regions of the brain. Specifically, fMRI revealed that there was a significant increase in the right ventral frontal areas of the brain. This increase in brain activity was strongest among participants who showed moderate to declining performance on the behavioral memory tasks (Persson et al., 2006).

While the studies discussed so far have shown how cognitive decline affects older adults with normal hearing, they have not looked at cognitive decline in older adults with a hearing impairment. Recently, Lin et al. (2013) published research from a longitudinal study in which participants were older adults, with and without hearing loss, who were followed for 11 years to measure cognitive function. Cognitive function was measured using the 3MS (The Modified Mini Mental State) scale for global function and the Digit Symbol Substitution (DSS) test for executive function. Testing for cognitive impairment occurred at years 5, 8, 10, and 11. The results indicated that participants who had hearing loss scored 41% worse on the 3MS and 32% worse on the DSS than individuals with normal hearing (Lin et al., 2013). Participants with hearing loss were also 24% more likely to develop cognitive impairments 6 years sooner than older adults with normal hearing. This suggests that hearing impaired older adults have accelerated cognitive decline compared to normal hearing older adults. The studies discussed so far have shown that cognitive decline can occur in healthy older adults and even more so in hearing impaired older adults. It is even more important to understand how these declines affect older adults in their daily lives.

Effects of Hearing Loss and Cognitive Decline on Everyday Life

A major complaint from older adults who suffer from hearing impairments is the inability to understand speech when they are talking to someone, even when using a hearing aid. As Lin et al. (2013) showed, this can increase the rate of cognitive decline. In addition, hearing loss and cognitive decline can both lead to difficulty in performing daily tasks. Crews and Campbell (2004) measured older adults’ Activities of Daily Living (ADLs) in a longitudinal study. Participants either had hearing problems, visual problems, or no sensory problems. Over the course of the study, participants were given the Second Supplement on Aging (SOA-II), a survey that asks about quality of life and performance of daily tasks. Over the course of 17 months following their initial visit, participants were asked to complete the SOA-II. Crews and Campbell (2004) found that older adults with sensory problems were 1.7 times more likely to report problems with imbalance and experience more falls compared to participants without sensory problems. Participants with hearing loss were also 1.6 times more likely to have difficulty walking, going outside, getting in and out of bed, and remembering to take their medication than those with sensory problems (Crews & Campbell, 2004). These same limitations were not as different when comparing people with hearing problems to people who had developed visual problems around the same time. However, increased difficulty in the performance in all of these factors can make daily life more challenging.

Sensory and cognitive function are also two main predictors of poor driving ability in older adults (Anstey, Wood, Lord, & Walker, 2005; Edwards et al., 2008). Driving is an activity that over 246 million people in the US perform every day (U.S. Bureau of the Census, 2010). For older adults, driving can be beneficial to mental stability and therefore it is important to understand how older adults can maintain their driving abilities for longer periods of time. Anstey and colleagues (2005) reviewed research on factors that predict driving cessation. Factors such as health issues, traffic accidents, and self-reported crash histories were reviewed. Overall, driving cessation predictors in older adults can be broken down into three main factors: cognition, sensory function, and physical function/medical conditions (Anstey et al., 2005). Similarly, Edwards and colleagues (2008) followed older adults for 5 years in a longitudinal study to measure driving cessation predictors. Along with physical health and sensory function, cognitive function was a significant factor in determining driving cessation. Participants who performed poorly on the Useful Field of Vision (UFOV) test, a speed of processing test that can predict numerous driving mobility outcomes, were more likely to encounter driving problems and completely stop driving by the end of the 5 years (Edwards et al., 2008). By identifying the predictive factors associated with driving cessation, research could eventually help older adults maintain their driving privileges, which could ultimately improve their overall health.

Research has shown that people who experience driving cessation show increased signs of depression (Edwards, Lunsman, Perkins, Rebok, & Roth, 2009; Fonda, Wallace, & Herzog, 2001; Ragland & Satarino, 2005). Fonda et al. (2001) found that depression was significantly higher in older adults who could not drive. When asked about the depressive symptoms, people responded by saying that their freedom had been taken from them. They had to rely on someone else to run their errands for them and take them to and from appointments. Similarly, Edwards and colleagues (2009) found that social functioning had significantly decreased in older adults who experienced driving cessation. For some individuals, a decrease in social activity on its own can lead to depression. When a loss of social activity and driving occur at the same time, the prevalence of depression is much higher.

While driving cessation can lead to mental and even physical impairments in older adults, hearing loss by itself can affect an individual's quality of life (Dalton et al., 2003; Tambs, 2004). Elderly people who have been affected by hearing loss tend to be less active and feel more depressed (Dalton et al., 2003; Tambs, 2004). Depression in older ages can lead to an increased risk for cardiovascular disease and other health problems (Elderon & Whooley, 2013; Suls & Bunde, 2005; Whooley, 2006). The combination of increased health risks from sensory and cognitive decline and driving cessation can be detrimental to an individual's health. The results from Edwards et al. (2008) showed that physical decline impacted health as much as mental decline in older adults who had lost the ability to drive. Older adults who are affected by driving cessation are also at greater risk for being put into assisted living facilities (Edwards et al., 2008). The health of older adults who live in assisted living facilities is known to decline much quicker than adults who live on their own (Mitchell & Kemp, 2000). It is beneficial to provide training to adults as they reach their older ages. Research is starting to show that training and mental exercises can slow age-related decline and even improve sensory and cognitive functions in older adults (Berry et al., 2010; O'Brien et al., 2013; Willis et al., 2006).

Neural Plasticity and Cognitive Training

The declines encountered by people as they age have typically been viewed as inevitable. For years, researchers believed that the brain was only malleable during the early stages of life (Huttenlocher, 2009). However, current research has shown that the brain is still "plastic" in the sense that it can continue to change even into the later years in life (Huttenlocher, 2009). The term plasticity refers to the brain's ability to create new neural connections (Burke & Barnes, 2006). In order to embrace and enhance plasticity, cognitive training programs are being developed that expose individuals to complex mental activities. Most cognitive training programs require participants to spend hours, days, or weeks completing the same or similar tasks (Ball et al., 2002; Dahlin, Nyberg, Bäckman, & Neely, 2008). Cognitive training can be done at any age, however its effectiveness is commonly studied in older adults. Dahlin et al. (2008) measured older and younger adults on their executive function abilities after cognitive training, whether age played a role in gains in cognition after training and if these effects would still be seen after 18 months. Executive function was measured on five types of tests; perceptual speed, working memory, episodic memory, verbal fluency, and reasoning. Following this, participants were trained for five weeks on five different tasks. The first four tasks included updating a single list of items that consisted of numbers, letters, colors, and spatial locations. The fifth task was a keep-track task in which participants were presented with words and were asked to categorize them (e.g. animals, clothes, countries, sports, or professions). At the end of each trial participants were asked to recall the last word in each category. Dahlin et al. (2008) found that after the training period, both younger and older participants performed significantly better in the first four tasks, suggesting that both age groups improved in executive function. In the keep-track task, younger participants performed better than older participants. However, older participants still performed significantly better than they did at baseline. After the 18 month re-assessment, both younger and older participants showed significantly higher scores from the baseline measure. Older participants' overall scores were even higher than the baseline scores of the younger participants. In other words, training improved executive function in both younger and older adults even after 18 months had passed (Dahlin et al., 2008).

In order to enhance specific areas of cognitive abilities, different types of cognitive training programs have been developed. Lustig, Shah, Seidler, and Reuter-Lorenz (2009) discuss three of the different program types that have been developed over the last few decades. One type of training discussed is strategy training. This training focuses on cognitive functions in which individual weaknesses are identified, then helps them improve performance in these areas (Lustig et al., 2009). For example, training by using the method of loci to increase memory performance is a form of strategy training (Lustig et al., 2009). In order to show the effectiveness, transfer, and durability of strategy training, Rebok, Carlson, and Langbaum (2007) performed a meta-analysis on 218 studies that used strategy training to help older adults with memory impairments. Overall, it was reported that only 39 of the studies provided evidence based support for strategy training. However, the durability and the transfer from the strategy training used varied. Durability in memory ranged from 1 to 6 months in these studies. It was also discovered that many individuals who learned a specific strategy (i.e. the method of loci), used that strategy to recall a list of words, but did not use it for anything else in their daily lives. Rebok et al. (2007) believe strategy training is still useful in older adults who are just starting to experience memory problems and can use a specific strategy to help them exercise their memory.

The next major type of cognitive training is process training. Process training provides individuals with a set of tasks that are thought to rely heavily on a specific type of cognitive process. Unlike strategy training, process training asks participants to focus on a task that is thought to be specific to a certain cognitive process (Lustig et al., 2009). For example, the speed of processing training from Edwards et al. (2008) helped participants on the UFOV and their overall driving abilities. Bherer et al. (2006) studied younger and older adults to see if attentional control could be improved. Participants were given an auditory discrimination task and a visual identification task both together and separately. The auditory task involved participants identifying whether a pitch was either high or low. In the visual task, participants were asked to look and identify whether they saw a “B” or “C” on the computer screen. A baseline measure was taken and then participants were given five blocks of training that included either the visual or the auditory task. The training then moved on to a mixed block that displayed a combination of the visual and auditory task at random. Bherer and colleagues (2006) found that both older and younger participants improved on both tasks (visual and auditory) in response speed (measured with reaction time) and response accuracy (number of correct answers) after training. Response speed for older and younger participants significantly decreased, while response accuracy improved significantly for both older and younger participants. More interestingly, older participants’ improvement in accuracy was much higher than that of the younger participants. Bherer et al. (2006) believe this shows that latent cognitive reserves exist in processing even in older adults.

It is also common for cognitive training programs to be assessed by how well the program transfers the abilities learned to everyday life. Process and strategy training typically struggle in transferring abilities, so a third type of training, known as multimodal approaches, combine different aspects of training to improve transfer (Lustig et al., 2009). Multimodal approaches are usually more complex than strategy approaches because they contain social components as well as cognitive ones. Stuss and colleagues are among the researchers who use multimodal approaches to help develop cognitive training programs. Stuss et al. (2007) combined strategy training with social aspects of daily life to create a three part program consisting of: memory, goal management, and psychosocial function. Before training began, participants were given several neuropsychological batteries to assess cognitive function (e.g. Digit Span Test, Logical Memory, Wisconsin Card Sorting Test (WCST), and Boston Naming Test (BNT)). Participants then completed 14 weeks of the training seminar, which included an introductory week, 12 weeks of actual cognitive training, and a closing seminar. The overall goal was for the participants to take as much as they could from their training and apply it to everyday situations. Stuss et al. (2007) found that with their multimodal approach to cognitive training, participants did better in multiple areas of life. Participants were able to develop, focus, and maintain their long term goals after training. For example, participants may have wanted to improve on taking care of themselves. After training, participants showed improvements in simulated real-life tasks, overall well-being, self-reported executive function, and memory. Specifically, the researchers believe this multimodal approach benefits episodic memory, which assists older adults in their daily activities (Stuss et al., 2007).

Issues Concerning Behavioral Approaches to Cognitive Training

As with most types of programs, there are strengths and weaknesses in cognitive training programs. The biggest issue is that cognitive training can result in training effects, where participants are just learning the task they are given over the period of time that they are trained and are not actually learning or improving a cognitive ability. In strategy-based training, for instance, it is common for participants to have large benefits specific to the tasks on which they were trained. However, these benefits are limited in their transfer to other types of training tasks (Lustig et al., 2009). Process training has shown promising results for the transfer of abilities to a large amount of different tasks, but the benefits from training requires close analysis for each of those tasks to determine which cognitive processes are being trained. It can also be difficult to distinguish which abilities are being transferred, so it is important to do a post-hoc task analysis to see where the abilities are being applied (Lustig et al., 2009). Multimodal approaches typically have the opposite pros and cons from process and strategy. Transfer effects can be widespread through a number of abilities but are often weaker in their effectiveness on a specific task (Lustig et al., 2009). Due to the complex nature of multimodal approaches, it can be difficult to know which part of the programs lead to transfer and which parts need to be emphasized. However, because multimodal tasks are so closely related to everyday living and social tasks, the training benefits still tend to be greater than with process or strategy training (Lustig et al., 2009). Even with some of the issues that occur with the behavioral methods of cognitive training, the multimodal approach has helped develop programs that are used for larger populations.

Combined Programs and LACE Training

Multimodal approaches of cognitive training have become one of the more preferred methods for designing a program. The idea that one program can be designed to fit all people in a certain population and can help them with their daily tasks. The Advanced Cognitive Training for Vital and Independent Elderly (ACTIVE) is a program that combines the methods of cognitive training with the aspects of daily life. The ACTIVE program helps older adults transfer learned abilities from training into everyday situations (Ball et al., 2002; Jones et al., 2013; Willis et al., 2006; Wolinsky et al., 2006). ACTIVE is considered a strategy approach by some but is also seen as a multimodal approach to cognitive training as well. The ACTIVE program was among the first to be used with a large-scale sample, which allowed researchers to divide participants into four groups (memory training, reasoning training, speed-of-processing training, and a control group) (Ball et al., 2002). Each of the three training groups received 10 weeks of training. All three groups showed signs of improvement in cognitive performance right after training was finished and after a five-year follow up. Ball and colleagues originally found that the improvement in cognitive abilities did not transfer over to participants' ability to perform everyday tasks. However, Willis and colleagues (2006) performed a follow-up study with ACTIVE participants and found that participants from the reasoning group reported significantly greater application of their cognitive abilities to performance on everyday tasks.

The ACTIVE program is commonly used because it shows a strong transfer of learned cognitive abilities to everyday situations. Edwards and colleagues (2009) looked at data from two different cognitive training programs (ACTIVE and SKILL). The SKILL training is similar to ACTIVE, except in that it includes people with dementia and other cognitive diseases. From these two trainings, participants' data was assessed to see if the speed of processing training (from both ACTIVE and SKILL) had an effect on the participants' ability to drive. The UFOV test and the Mobility Driving Habits Questionnaire were used to assess participants' driving ability before and after training. Participants who completed the speed of processing training were 40% less likely to stop driving within three years of the initial training. This means that the speed of processing training can transfer to driving and delay cessation (Edwards, Delahunt, & Mahncke, 2009). Even though the ACTIVE program has shown good transferability to everyday tasks, other programs are still needed to help with abilities that ACTIVE does not cover.

While the ACTIVE program is commonly implemented among older adults, it is limited in the range of abilities that can be trained. As previously mentioned, ACTIVE uses memory training, reasoning training, and speed-of-processing training to teach skills. However, the ACTIVE program does not help older adults with hearing impairments. Listening and Communication Enhancement (LACE) is a program designed to help older adults with hearing aids improve their listening and comprehension skills (Sweetow & Henderson-Sabes, 2004). The program focuses on hearing, listening, comprehension, and communication in older adults. In one of the early studies of LACE, participants were given training that consisted of Speech in Babble, Time Compressed speech, Competing Speaker, Target Word, and Missing Word. The Speech in Babble task requires participants to identify words among multi-talker babble sounds (Sweetow & Sabes, 2006). Time Compressed speech is the same as Speech in Babble, except that the stimuli are presented at an 85% faster rate. The Competing Speaker task is again similar to the Speech in Babble task, but with only a single speaker in the background. The Target Word task is an auditory working memory task that involves a visually presented target word and an auditory sentence. The participant first sees a target word and then listens to a sentence in which the target word occurs. The participant is then asked to choose the target word from a forced alternative choice selection. The Missing Word exercise involves presenting the participant with a sentence but masking one word with environmental noise (i.e. road sounds, construction sounds, emergency vehicles, etc.). The participant's goal is to identify the word that was masked. The researchers found that participants improved significantly over the four weeks in all of the test areas. A year later, Sweetow and Sabes performed a follow up study that replicated the results and showed that participants only needed two weeks, as opposed to 10 weeks, of LACE training in order to reach the desired level of learning (Sweetow & Sabes, 2007).

More recently, Olson, Preminger, and Shinn (2013) investigated the effectiveness of LACE training in participants with and without hearing aids. Olson and colleagues measured participants who were old (had been using) and new (never used) to hearing aids on the LACE training. Each participant was asked to complete 10 sessions of training and then asked to come back after a follow-up period. Olson and colleagues found that participants who were new to hearing aids showed an improved ability in speech-in-noise tasks after just two weeks of training. Over half of participants who were old to hearing aids also showed signs of improvement after just two weeks of the LACE training. Both hearing aid groups performed better than the control group who were also new to hearing aids but did not experience any training (Olson et al., 2013).

As previously mentioned, behavioral methods to cognitive training are limited in the gains that come from training. Among some of these limitations is knowing whether or not participants adhere to the programs, specifically when they are given tasks that can be completed at home (Chisholm et al., 2013). Chisholm and colleagues (2013) investigated how high adherence was to LACE training at home and found that participants still completed training tasks about 86% of the time. Regardless of adherence, behavioral methods used to study LACE and other cognitive training programs leave too many confounding variables that were previously mentioned. This is where it becomes important to study the neurophysiological aspects of the training as well as the behavioral ones.

Neurophysiological Evidence in Cognitive Training

Advances in neurophysiological measurement technology have allowed researchers to visually observe areas of the brain and to measure complex cognitive processes that occur in neurons that cannot be detected through behavioral methods. One of the most well-known forms of neurophysiological measurement is functional magnetic resonance imaging (fMRI). Studies that use fMRI allow researchers to see different areas of the brain that become more active, less active, or completely inactive when a given task is performed. Research using fMRI has given researchers the ability to see brain localization of auditory function and hearing loss in older adults (Peelle, Troiani, Grossman, & Wingfield, 2011). fMRI research has also elucidated some of the changes that occur with cognitive training (Jäncke, Gaab, Wustenberg, Scheich, & Heinze, 2001). For example, Jäncke and colleagues (2001) investigated whether the auditory cortex reflected changes due to cognitive training and if it did, which areas of the cortex changed after training occurred. Participants were split into a training and no training group and then given an auditory oddball task with concurrent fMRI recording. The oddball task consisted of a standard tone played at 950 Hz with three target stimuli played at 952, 954, and 958 Hz throughout the standard tone. The results showed that participants in the no training group had significantly more activation in the superior temporal gyrus (STG) than those in the training group. This is important because the STG contains the primary auditory cortex, which is responsible for processing sounds. Jäncke and colleagues (2001) believe that increased STG activation means there are more auditory resources used in the brain to process the stimuli. In other words, the group that received training was able to detect the sounds at the 954 and 958 Hz level and did not need to spend as many resources processing the stimuli. While the results from the Jäncke et al. (2001) study are able to show the localized changes in the STG, they were not able to show the temporal changes in amplitude from the neuronal responses. fMRI does not allow for the investigation of sensory, perceptual, and cognitive processing with millisecond precision. This kind of high temporal resolution would allow for the study of early information processing and the transition of sensory processing to higher cognitive function that is necessary to navigate the stimulus heavy environment of daily life. For this reason, it is important to use other methods of neurophysiological measurement.

Electroencephalography (EEG) is a measurement of neurophysiological response that allows researchers to measure the electrical activity of the brain via scalp electrodes when a given task is performed. An event related potential (ERP) reflects the underlying sensory, motor, and cognitive processes that accompany thought and behavior when the task is performed (Luck & Kappenman, 2011). While ERPs do not allow for the localization of brain activity, they are a valuable measurement of brain function because they allow researchers to measure the neural responses within milliseconds (ms) of an activity occurring (Luck & Kappernman, 2011). ERPs result in a series of positive and negative wavelengths that indicate the occurrence of an event. The timing of these neural responses indicate the occurrence of different psychological functions such as attention, working memory, and the processing of sensory information.

The positive and negative wavelengths are identified by their peaks over the first few milliseconds when a task is performed. The first peak occurs around 100 – 130 ms and is known as the P100 or P1. The P1 is thought to represent the suppression of unattended information as well as the general level of arousal (Key, Dove, & Macguie, 2005). With auditory stimuli, the P1 has been associated with auditory inhibition. The inhibition of sounds occurs with the sharpening of auditory stimuli for needed for response and ignoring irrelevant sounds in the environment. This has been shown to decrease in amplitude in the P1 (Key et al., 2005). The next peak is negative going, can occur around 100 – 200 ms, and is known as the N100 or N1. The N1 is a sensory response that is invoked by auditory or visual stimuli. The amplitude has been shown to be affected by spatial attention but tends to be even larger when an individual performs a detection task (Luck, 2005*)*. This is thought to be due to some form of discrimination processing (Luck, 2005). The positive going peak following the N1 is known as the P2 and commonly occurs with the N1, also known as the N1/P2 complex. The P2 tends to be sensitive to the physical aspects of stimuli, such as pitch and tone in auditory stimuli (Key et al., 2005). It is also thought that the P2 amplitude changes with different cognitive tasks such as selective attention, short term memory, and feature detection (Key et al., 2005).

Following the N1/P2 is the negative going peak, N200 or N2, which has been associated with stimulus discrimination, orienting response, and target selection (Key et al., 2005). The N2 is made up of several subsets known as the N2 family. Among these subsets are the N170, which is associated with the processing of human faces. The other subset of the N2 family is Mismatch Negativity (MMN), which does not require the focus of attention on a stimulus. This makes the MMN a common measure for test-retest reliability and sleep studies (Key et al., 2005). In auditory stimuli, MMN is thought to show pre-attentive sensory memory and is commonly used to measure an individual’s ability to discriminate linguistic stimuli (Key et al., 2005). After the N2 family, the most extensively researched peak is the P300/P3. Like the N2 family, the P3 has subcomponents that are believed to represent the various aspects of attention, amount of resources processing, and memory updating (Key et al., 2005). The P3b, a subset of the P3, has been shown to be elicited by the oddball paradigm, when a target stimulus is presented infrequently among a series of more frequent distractor stimuli (Luck, 2005). The P3b has been shown to have shorter latencies in response to auditory stimuli than visual stimuli. A second subset of the P3 is the P3a, which is associated with involuntary attention as well as inhibition and has been shown to be elicited by Go No-go tasks. In this paradigm, amplitude is usually larger in the No-go condition compared to the Go condition (Key et al., 2005). Research on ERP components shows that they can be invoked by multiple stimuli, different paradigms, and tap into different types of cognitive processes. This allows researchers to measure a wide range of psychological functions among neural firings.

Researchers use ERPs with cognitive training to measure the different effects training has on perceptual and cognitive abilities. For instance, Berry et al. (2010) looked at improving perceptual abilities in working memory (WM) in older adults. Participants were trained over a five-week period on two perceptual tasks and a WM task. The perceptual tasks involved the participant clicking one of two buttons indicating whether or not they had seen an image increase or decrease in size. These tasks were also presented in different colors and participants were asked to recall which color the previous task had been in addition to the size perception task. Berry et al. (2010) found that participants who underwent training were likely to show a decrease in the N1 peak amplitude. These results are consistent with research that shows that with training, neural peaks become smaller (Alain & Snyder, 2008; Ding, Song, Fan, Qu, & Chen, 2003), suggesting that trained visual stimuli elicit smaller EEG waves in humans. The decreased amplitude of the N1 is representative of perceptual gains within WM in older adults. In other words, N1 performance is consistent with the idea that increased performance on perceptual tasks frees up WM to store more information (Berry et al., 2010). In order for this training to be successful, strategy-based training on specific tasks is needed to increase WM performance. While the training benefits may not transfer directly to everyday tasks, improving WM can still be beneficial in daily activities.

Current research on ERPs and cognitive training focuses primarily on visual stimuli. ERPs have been used in studies that measure auditory attentional decline (Finnigan, O’Connell, Cummins, Broughton, & Roberston, 2011; Getzmann, Gajewski, & Falkenstein, 2013; Manan, Franz, Yusoff, & Mukari, 2013) and auditory perception (Ghemlin et al., 2011; Passow et al., 2012). However, few studies look specifically at the effects of cognitive training on auditory stimuli. Tremblay, Kraus, McGee, Ponton, and Otis (2001) measured the N1 and P2 wavelengths in adults to see if speech-in-sound recognition would improve with cognitive training. Participants were given different pitches of the tone “ba” and were asked to distinguish this sound among various noise at different speed intervals. The results showed that participants had an increased amplitude in the N1 and P2 peaks, following training. According to Tremblay et al. (2001) the peaks’ increase in amplitude suggests that there is more neural synchrony occurring when participants have learned to distinguish the “ba” sound from the rest of the noise. In other words, the increased amplitudes in the N1 and P2 peaks resemble the neural firings of learned stimuli. This suggests that training has a significant effect on early sensory processing of auditory stimuli (Tremblay et al., 2001).

Research on the early ERP peaks gives insightful information about sensory differences in training. However, it is important to see what happens after sensory information is processed and for this many researchers look at the P300/P3 peak. As previously mentioned, the P3 typically peaks when there is a surprise or oddball stimulus introduced during a task (Luck, 2005). O’Brien and colleagues (2013) investigated how the N2pc and P3b amplitudes (subsets of the N2 and P3) would change after cognitive training. Participants were trained over a 10 week period on different visual search tasks, which were adaptive in difficulty depending on individual performance. The tasks in the training included identifying orders of visual sweeps, visual discrimination of surrounding targets, tracking and remembering visual targets, discriminating a center target while locating a peripheral target, and detecting and remembering targets. O’Brien et al. (2013) found that after training there was a significant increase in amplitude of the N2pc and P3b peaks in response to visual stimuli. This increase did not occur in the control group with no training. These results suggest that training can increase the attentional capacity (P3b) and processing capacity (N2pc) in older adults (O’Brien et al., 2013). Process training was used to train participants across a variety of tasks in order to transfer the gains from training to everyday situations. Regardless of the type of training used, this study and the previously mentioned studies all provide evidence that age-related decline can be reversed.

Increased vs. Decreased ERP Amplitude in Cognitive Training Studies

The results from Tremblay et al. (2001) varied from O’Brien et al. (2013) and Berry et al. (2010) in very different ways. First, Berry et al. (2010) and O’Brien et al. (2013) used visual stimuli in their studies, while Tremblay et al. (2001) used auditory stimuli. The presentation of visual and auditory stimuli have been known to elicit different peak amplitudes and latencies from one another (Key et al., 2005). Second, Berry et al. (2010) found that amplitudes of the ERP components decreased after training had taken place, while the research by Tremblay et al. and O’Brien et al. showed an increase in amplitude after training. There is no clear definition as to whether or not an increase or decrease in amplitude shows the effects of training. Either outcome can be supported by the research. However, going back to the research on attentional resources and decline in older adults, a decrease in amplitude would be expected. For example, Kok (2000) reviewed research on age-related changes in attention through ERP components. The research showed that when a task was more complex (i.e. required more attentional resources), ERP amplitudes (from N1 to P3) typically increased (Kok, 2000). Therefore, training should improve attentional resources and decrease the ERP amplitude. For further evidence, recall the Jäncke et al. (2001) study where fMRI revealed a decrease in activation of the STG after training. Even though ERPs do not localize neuron activation, they still measure the amount of neuronal activity occurring during an event. With this evidence, we would expect to see a decrease in amplitude after cognitive training has occurred.

Attentional Blink and ERPs as a Measure of Cognitive Decline

As previously established, older adults have difficulty dividing, focusing, and inhibiting information from their attention (Craik & Salthouse, 2011). This can be dangerous for older adults, particularly when it comes to driving (Edwards et al., 2009; Edwards et al., 2008). Driving requires visual and auditory abilities in order to see and maneuver around complex traffic situations. The speed at which many of these situations occur is very quick, therefore it is useful to have a measure that can test the temporal aspects of attention in older adults. The attentional blink (AB) phenomenon, first noted by Raymond, Shapiro, and Arnell (1992), occurs during a rapid serial visual presentation (RSVP) of stimuli when a first identifying target is presented and a second target is presented too quickly after the first for an individual to detect. An AB occurs because too many attentional resources are used on a first target (T1), leaving attentional resources briefly unavailable for detecting a second target (T2). In other words, the AB reflects the competition between two targets for WM encoding, episodic registration, response selection, target representations, and inhibition of distractors (Dux & Marois, 2009). The use of the RSVP allows researchers to measure the unique temporal properties of attention.

It is also a good measure of age-related cognitive decline because it has been shown that the AB effect tends to get worse after the age of 40 (Georgiou-Karistianis et al., 2007).

Slawinski and Goddard (2001) made use of an AB task to see the age-related differences in the processing of auditory tones in younger and older adults. The AB task was used in line with the idea that older adults have greater difficulty inhibiting information from their attention when trying to process a different stimulus (Alain & Woods, 1999). Participants were divided into two conditions (control and experimental), where the control condition was given a dual auditory AB task in which participants were presented with a target sound (T) and asked to identify that same sound again during rapid auditory presentation (RAP) of stimuli. The experimental condition was presented with the same target but with a different probe (P) sound that had different stimulus onset asynchrony (SOA) lengths from T1 to T2. Older adults performed much worse at identifying P when it occurred in the RAP regardless of SOA. The AB effect was significantly greater for the older adults when compared with the younger adults. Slawinski and Goddard (2001) believe these results suggest that older adults have greater trouble inhibiting information from their attention. While this study shows that older adults are slower at performing an AB task behaviorally, it does not show the changes (if any) that are occurring in the AB on a neural level.

Much of the existing research using an AB paradigm and ERPs focuses on the age-related changes of attention in older adults. Cona, Bisiacchi, Amodio, and Schiff (2013) compared younger and older adults on an AB paradigm to see if there were differences in the capacity of attentional resources, the ability to inhibit irrelevant stimuli, and if older adults took longer to process stimuli. The RSVP contained a continuous stream of 500 black letters with 75 target letters presented among them. Participants were asked to press the space bar whenever an “X” or

“Y” appeared. Behavioral results showed that reaction times were much slower for older adults than for younger adults. ERP analyses showed that the N2 and P3a latencies were significantly later in older adults compared to younger adults for T1 and T2. The increased latencies of the N2 and P3a support the behavioral results that older adults take longer to process stimuli in an AB paradigm. The amplitude for T1 was greater in older adults than in younger adults. The amplitude for T2 was the reverse, greater for younger adults than older adults. Cona and colleagues suggest that this represents older adults’ need to use more attentional resources for the first target and do not have as many resources to process the second target. Finally, Cona et al. (2013) believe that these increased latencies and amplitudes in the N2 and P3a in older adults is synonymous with older adults’ difficulty inhibiting and shifting attention. The research using AB paradigms and ERPs is insightful for exploring the age-related changes in cognitive decline. However, there is minimal research on cognitive training and the use of ERPs and an AB task.

Aims of the Current Study

Studies have shown that cognitive training can reverse the effects of age-related cognitive decline in older adults (Berry et al., 2010; Dahlin et al., 2008; O’Brien et al., 2013). This could potentially be helpful in bolstering older adults’ driving abilities (Edwards et al., 2008) and ultimately, their physical health (Dalton et al., 2003; Tambs, 2004). Attentional processes such as the inhibition of attention and the allocation of attentional resources has been known to decline with age (Craik & Salthouse, 2011). These declines in attentional function can cause problems for older adults who drive because they may not be able to process the complex traffic situations that occur on the road. It is important to be able to focus attention and block out unwanted stimuli quickly when driving. Enhancing an individual’s ability to hear speech may help slow and even reverse the effects of age related cognitive decline. The current study examines the effects of LACE training on older adults' ability to hear speech in noise. Using an AB task is helpful for these situations because it is a way to measure attention in a rapid temporal presentation of stimuli. It is also useful because it has been shown that after the age of 40, older adults have slower reaction times when performing an AB task (Georgiou-Karistianis et al., 2007). Although the AB paradigm has been used extensively to study visual attention, there is minimal research of its use on auditory attention and cognitive training.

In this study, participants were tested on an auditory AB paradigm for a baseline measure, a pre-training measure after 10 weeks of no contact (thus creating a within-subjects control condition), followed by LACE training, and finally, a post-training after the completion of the training. EEG measurements during the AB task shows performance of the P3a before training, at the baseline and pre-training measure and after training at the post-training. Changes in the P3a component will show differences in attentional and cognitive performance. In all, participants completed three sessions (baseline, pre-training, post-training) and LACE training occurred in-between the second and third sessions. The P3a is not expected to change from the first to second session, as there was no intervention during this time. However, a change is expected to occur from the baseline to post-training measure as well as the pre-training to post-training, indicating a change in attentional awareness and cognition.

Method

Participants

Eighteen older adults (10 females) were recruited by the School of Aging Studies at the University of South Florida Tampa. Informed consent was obtained for all participants prior to their participation. Participants' ages ranged from 64-84 years (*M*= 70.44, *SD*= 6.46). All had adequate cognitive status; Mini-Mental State Examination (MMSE) > 24 (Folstein, Folstein, & McHugh, 1975) and no history of neurological disease. All participants were fluent English speakers. None of the participants reported completion of any previous auditory or cognitive training programs. All participants were high school graduates and had at least some college experience (education in years; *M*= 16.11, *SD*= 2.14). Pure tone hearing thresholds indicated that the primary hearing configurations were sloping high frequency hearing loss with no evidence of a conductive component per normal type A tympanograms. Pure tone averages (PTA) mean = 23.33 dB HL (range 10.00-43.33 dB HL) for the right ear and mean = 19.09 dB HL (range 8.33-46.67 dB HL) for the left ear. High frequency PTA mean = 37.95 dB HL for the right ear and mean = 33.18 dB HL for the left ear.

Listening and Communication Enhancement (LACE) Training

Training sessions for LACE were completed in a computer lab in the Department of Communication Sciences and Disorders building at the University of South Florida Tampa. Training classes were 2-3 times per week. Participants had the opportunity to finish 1-2 training sessions per visit with each training session approximately 20 minutes in duration. Participants each completed 20 training sessions in total. Each session included five modules that focused on degraded speech and cognitive skills. A detailed description of the training modules is provided in Table 1.

Table 1. LACE Training Modules and Descriptions

Exercise	Description
Speech in Multi-talker Babble	Identify and repeat primary sentence in the presence of multi-talker speech babble. Score determined by self-reported accuracy and intensity of multi-talker speech babble.
Rapid Speech	Identify and repeat time compressed sentence and answer questions. Score determined by self-reported accuracy and speed of speech signal.
Competing Message	Identify and repeat primary sentence and answer questions in the presence of a competing talker. Score determined by self-reported accuracy and intensity of competing message signal.
Missing Word	Determine omitted word from sentence based on contextual cues. Score determined by accuracy and time of response.
Target Word	Identify and recall word preceding/proceeding target word. Score determined by accuracy and time of response.

The modules were adaptive with the level of difficulty increasing or decreasing based on the accuracy of the previous response. Scores and progress were repeated back to the participant following each training module. Participant time and performance were recorded at the end of each training session.

Attentional Blink Paradigm

The Attentional Blink (AB) paradigm consisted of 480 trials (approximately 1hr duration). The stimuli were presented binaurally via ER-3a insert earphones and were comprised of a sequence of monosyllabic words, white noise, and silence presented along with a continuous segment of multi-talker babble. One channel of the two channel stimulus contained the following sequence of stimuli presented at 70dB HL: Target 1 (T1) a spoken digit (numbers 1 through 9, excluding bisyllabic 7), an interstimulus interval (ISI) of white noise masker of 150 ms (short ISI) or 400 ms (long ISI), target 2 (T2) a spoken 350 ms monosyllabic word given in Appendix 1 (NU. 6; Tillman & Carhart, 1966, PB-50; Egan, 1948, & W-22; Hirsh, Davis, Silverman, Reynolds, Eldert, & Benson, 1952) represented as the deviant or 350 ms silence represented as the standard each with equal probability of occurrence, and a 150 ms white noise masker. The other channel contained a continuous segment of multi-talker babble that was either 1500 or 1750 ms in duration to match the duration of the other channel and began 500 ms prior to the stimuli in the other channel. A signal-to-noise ratio was maintained 5 dB above each individual participant's WIN score to ensure perceptibility (Wilson, 2003; Wilson, Abrams, & Pillion, 2003; Wilson, Carnell, & Cleghorn, 2007). The 480 trials were presented equally in one of four stimuli sequences: 1. T1, short ISI, deviant T2, and masker; 2. T1, short ISI, standard T2, and masker; 3. T1, long ISI, deviant T2, and masker; 4. T1, long ISI, standard T2, and masker. Figure 1 demonstrates the stimulus sequence for T1, short ISI, deviant T2, and masker.

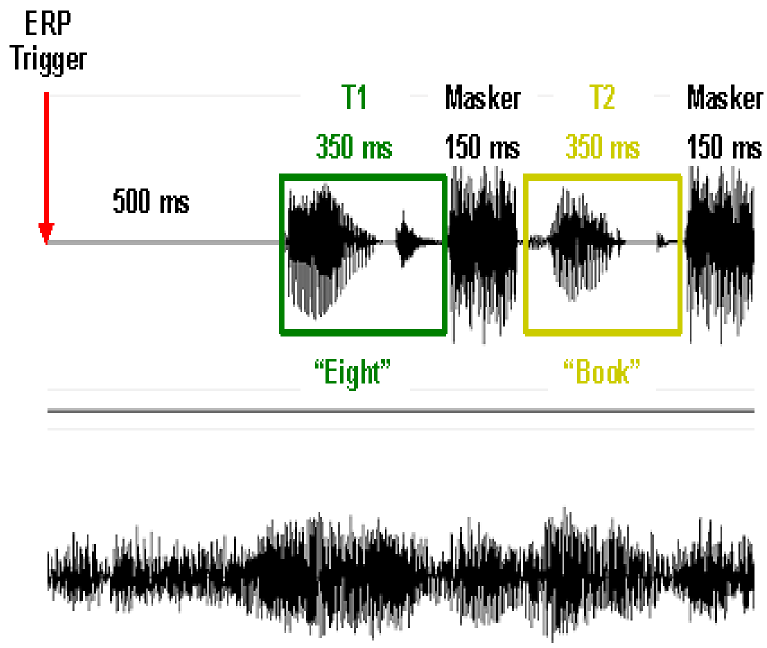

Figure 1. Presentation of AB Paradigm. Upper panel shows stimulus sequence for the AB: T1 a spoken digit, 150 ms short ISI masker, T2 a 350 ms spoken word, 150 ms masker. Lower panel shows background of multi-talker babble.

Following each trial, the participants responded using keys on a keyboard to prompts on a computer, designating T1 as an odd or even number and determining whether T2 matched a written word displayed on a computer monitor or not.

Procedure

ERPs were obtained in the auditory modality using an AB paradigm in three sessions: 1. A baseline session scheduled 10 weeks prior to LACE training; 2. A second session (pre-training) scheduled one week prior to LACE training; and 3. A third session (post-training) scheduled one week following LACE training completion. In this way, each participant served as his/her own control. The experiment took place in a dimly lit, sound-attenuating booth. Figure 2 represents the timeline of this procedure.

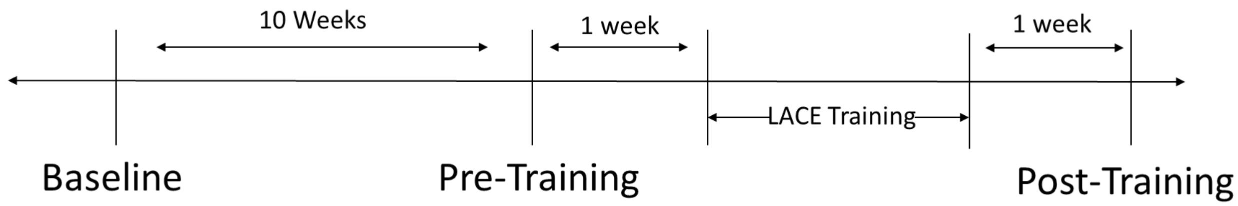

Figure 2. Timeline representation of testing and training procedure. Participants were not contacted during the 10 week period between Baseline and Pre-Training sessions. Participants started LACE training 1 week following the Pre-Training session, then were asked to come back for a final Post-Training session 1 week after the LACE training had been completed.

Apparatus

A Pentium 4 PC running E-Prime 1.1 (Schneider, Eschman, & Zuccolotto, 2002) hm recorded behavioral data and presented visual search stimuli on a 43 cm LCD monitor (60 Hz refresh, 1024 × 768 resolution) with a viewing distance of 90 cm. Responses were registered using a keyboard.

Electroencephalography Recording and Analysis

Continuous EEG activity was recorded using the NuAmps (NuAmp, Neuroscan, Inc., El Paso, TX) single-ended, 40-channel amplifier according to the NuAmps International 10–20 electrode system using a Quikcap with sintered Ag/AgCl electrodes, and a continuous acquisition system (Scan 4.3 Acquisition Software, Neuroscan, Inc.). A right mastoid electrode was used as a reference. Four additional electrodes were placed the outer canthus of each eye and on the supra and infraorbital ridges of the left eye to monitor eye movement and blink activity. The EEG was sampled at 1000 Hz. Electrode impedances were kept below 5 kΩ for most electrodes. Continuous EEG was high-pass filtered at a corner frequency of .1 Hz. Ocular artifact from eye movement and blinks were corrected for each participant by extracting the electroocular signals from the EEG.

EEG for correct T1-response trials was separated into epochs of 2000 ms (-300 ms before trial onset to 2300 ms after) and low-pass filtered at a corner frequency of 30 Hz with a squared Butterworth zero-phase filter (12dB/octave roll-off). Epochs in which EEG amplitude exceeded criteria of ±125µV were rejected prior to averaging. Data were then averaged separately for each stimulus type (present, absent) for short and long ISI conditions; re-referenced to averaged mastoids; truncated to a critical interval of -150 – 600 ms; and baseline corrected (-150 to 0 ms). P3a mean amplitude was measured at frontal electrode site Fz for present and absent stimuli in a 250 – 550 ms post-stimulus time window.

Data Analysis Plan

The following data analyses used in this study are secondary analyses based on data provided by Dr. Jennifer O’Brien from the University of South Florida St. Petersburg, in conjunction with the School of Aging Studies at the University of South Florida Tampa.

Behavioral performance for the AB task was at ceiling, meaning that scores were at their highest for all participants at all three testing time points and therefore is not reported. Overall mean differences between amplitudes at all three session times (Baseline, Pre-training, and Post-training), and by short and long SOA, were compared in a factorial ANOVA in IBM SPSS 22. This framework allows for the comparison of the Time x SOA interaction to see if SOA performance varied over time. An alpha of .05 was set for each measurement. Equal variances were assumed among the groups, with support being provided by Levene’s test of homogeneity ($p = .05$). Because sphericity was not assumed among the groups, Greenhouse-Geisser corrections were employed. In order to measure the means of short and long SOA individually across time, two omnibus one-way ANOVAs were used. This allowed the performance on short SOA to be measured across time without interference from the means of the long SOA. The same procedure was done in reverse to measure the long SOA across session times. If either of the one-way ANOVAs provided significant results, post-hoc *t*-tests were used to see where specific differences occurred across the different session times and each SOA length.

Results

Descriptive Analyses

The present sample consisted of 18 total participants that were close to even distribution by gender with 55.6% Female and 44.4% Male. Similarly, all participants were of White/Caucasian (100%) ethnicity and had at least some college education. Age, gender, education, and ethnicity did not affect P3a performance on short or long SOA. Even though there was a fairly equal amount of male and female participants, neither gender was more likely to differ in P3a amplitude. Also, the number of years of education an individual obtained did not affect P3a performance on SOA. For all correlations between demographic factors and SOA performance across sessions, see Table 2.

Table 2. Correlations of Descriptive Factors and P3a Performance on SOA across Sessions

	Age	Gender	Race	Education
Short SOA at Baseline	-.28	-.34	-	.11
Long SOA at Baseline	.01	.01	-	-.07
Short SOA at Pre-Training	-.11	-.21	-	-.24
Long SOA at Pre-Training	.08	.15	-	-.02
Short SOA at Post-Training	-.07	.19	-	.18
Long SOA at Post-Training	-.03	-.06	-	.28

Note. *Represents a significant correlation at the .05 level. Race did not produce correlations due to the entire sample being one Race.

Time and SOA on P3a Amplitude

A 2 x 3 within-subjects factorial analysis of variance (ANOVA) was run to see if Time (baseline, pre-training, post-training) x SOA (short and long) had an effect on participants' P3a amplitude. For means and standard deviations of the mean amplitudes for all sessions, see Table 3.

Table 3. Means and Standard Deviations for Short and Long SOA across Sessions

	Baseline	Pre-Training	Post-Training
	M(*SD*)	*M*(*SD*)	*M*(*SD*)
Short SOA	2.01(2.38)	.94(1.61)	-.06(2.25)
Long SOA	.36(1.56)	-.35(1.81)	.10(5.47)

The results show that the interaction of Time x SOA was not statistically significant, which may have been underpowered because interaction effects can be difficult to detect, *F*(1.23, 20.97) = 1.19, *p* = .300, *d* = .36, *r* = .18, 95% CI [-.32, 1.05]. There was also no main effect of time, *F*(1.28, 21.70) = 2.22, *p* = .146, *d* = .50, *r* = .24, 95% CI [-.19, 1.18]. This suggests that a significant change in P3a amplitude was not detected over time. However, the main effect of SOA was *approaching* significance *F*(1.00, 17.00) = 4.05, *p* = .060, *d* = .67, *r* = .32, 95% CI [-.03, 1.37]. These results suggest that when all other factors are removed, the type of SOA may show a change in participants' P3a performance.

With the main effect of SOA approaching significance, two omnibus ANOVAs were run to see if there was really a difference between short and long SOA performance. A one-way within-subjects ANOVA was run on short SOA performance across sessions. The results were statistically significant *F*(2,34)= 8.40, *p* = .001, *d* = .97, *r* = .43, 95% CI [.25, 1.68]. This suggests that P3a mean amplitude on the short SOA changed over the session times (follow-up post-hoc analyses in next section). A one-way within-subjects ANOVA was also run on long SOA across sessions. The results were not statistically significant, *F*(1.12, 19.02) = .22, *p* = .670, *d* = .16, *r* = .08, 95% CI [-.52, .83]. These results suggest that P3 mean amplitude on the long SOA did not change across sessions.

Post-Hoc Analyses

After finding a significant change in short SOA amplitudes across sessions, post-hoc analyses were run to see in which sessions these differences occurred. Figure 3 shows the differences in mean amplitude across all three sessions.

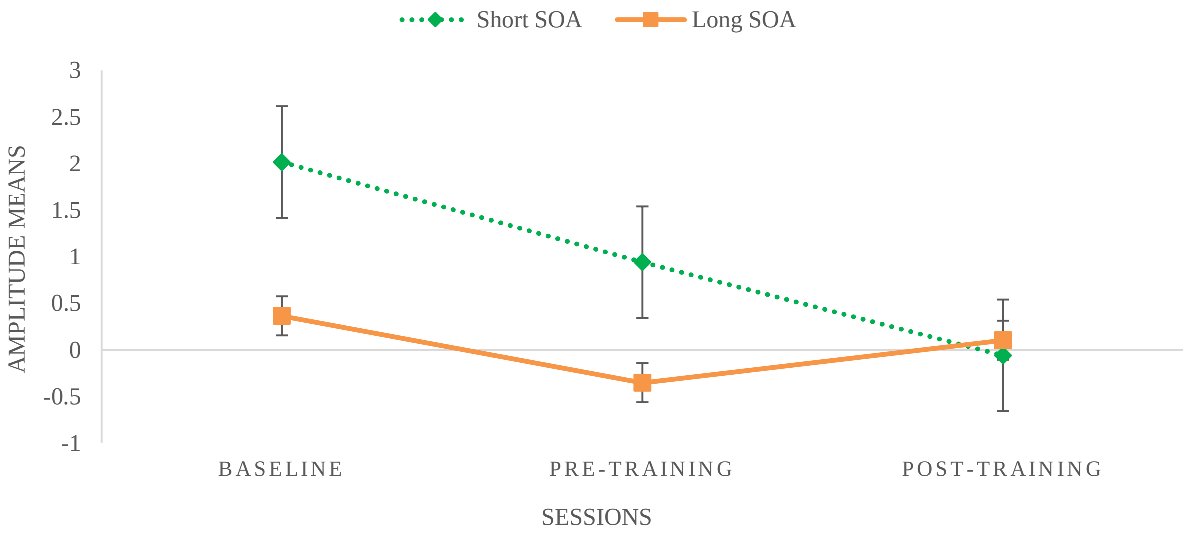

Figure 3. P3a Mean Amplitude across Sessions. Mean amplitude is significantly different at Baseline and Pre-training, which is before training occurred. After training (in the Post-training), mean amplitudes are near the same.

A paired sample *t*-test was run on the mean amplitudes of the short and long SOA at baseline. The results were statistically significant, *t*(17) = 2.25, *p* = .038, *d* = 1.09, *r* = .48, 95% CI [.11, 3.20]. This suggests that mean amplitudes on the short SOA were significantly different from amplitudes on the long SOA at the baseline session. A paired sample *t*-test was then run on the mean amplitudes of the short and long SOA from the pre-training. The results were statistically significant, *t*(17)= 2.77, *p* = .013, *d* = 1.34, *r* = .56, 95% CI [.31, 2.28]. These results suggest that the mean amplitudes of the short and long SOA were significantly different from each other in the pre-training session. Finally a paired sample *t*-test was run on the mean amplitudes of the short and long SOA at the post-training session. These results were not statistically significant, *t*(17)= -.14., *p* = .893, *d* = -.07, *r* = .03, 95% CI [-2.69, 2.36]. These results suggest that while P3a mean amplitude for short and long SOA were significantly different at baseline and pre-training, these differences were no longer detected at the post-training session.

Discussion

The goal of the current study was to see if changes to the P3a ERP component would occur in older adults after LACE training. These changes would serve as a benchmark to determine if there were any observed underlying neural gains and processes after LACE training was completed. Research has shown that the brain is malleable even into the later years in life (Anderson & Kraus, 2013; Berry et al., 2010; Jones et al., 2006; O’Brien et al., 2013). Using electrophysiological methods, this study has given support to the notion of the reversal of age-related cognitive decline. Older adults’ auditory attention was improved in an AB paradigm after LACE training had taken place. The amplitude of the P3a component decreased significantly after training for the short SOA and was nearly equal to the amplitude of the long SOA.

While significant results were uncovered for the key variables of time and SOA, several hypotheses were not supported by significant results. In particular, the results of the initial SOA and time analyses were not significant. This could have been due to the lack of change in amplitude from the long SOA overpowering the small SOA. Further inspection of the data revealed no significant change in long SOA even after training, supporting the hypothesis of this study. If a change in amplitude were uncovered in the long SOA, this may indicate the occurrence of cognitive decline or a lack in benefits from training. Further analyses showed that, as expected, the short SOA amplitudes decreased across sessions, specifically after training had taken place.

The current findings show decreased P3a amplitude after training, which supports the idea that age-related cognitive decline can be reversed. These findings coincide with those of Berry et al. (2010), who found that the N1 amplitude decreased after training and allowed for an increase in working memory performance. As previously established, there is some discrepancy in whether or not increased or decreased ERP component amplitude shows the effects of training in EEG studies. The results of this study support the idea that a decrease in amplitude shows signs of neural plasticity. One explanation could be the type of stimuli that were used, because visual and auditory stimuli have been known to elicit different strengths in ERP amplitude. However, in some research when visual stimuli were used (O'Brien et al., 2013) and in other research when auditory stimuli were used (Tremblay et al., 2001), there was still an increase in amplitude after training, which would not support the idea that the variation in stimuli could be the issue.

It is also possible that the variation between increase and decrease in ERP amplitude is connected to the nature of the task. Research has shown that ERP amplitude can be affected by multiple factors including the difficulty of a task and the presentation speed (Comerchero & Polich, 1999; Philiastides, Ratcliff, & Sajda, 2006; Polich, 2007). According to Polich (2007), when people are required to use more attentional resources, they tend to show a decrease in P3a amplitude. This is also the case when a target to target interval (TTI) is shorter compared to a longer TTI (Polich, 2007). Results from the current study showing a decrease in amplitude coincide with this previous research; given that a rapidly presented AB paradigm and decrease in amplitude was seen across sessions for the short SOA, which has a shorter TTI than the long SOA. An increase in amplitude from this task might be the marker of cognitive decline rather than cognitive gains. These results also match other studies that did not use a rapid presentation of stimuli. In O’Brien and colleagues (2013), P3b amplitudes were larger for the training group as compared to the control group. This may be due to the visual task search that was used. While the task was timed, and participants were asked to respond as quickly as possible, the TTI was much longer than if participants had been presented with an AB paradigm. Ultimately, it is still unknown as to why some researchers report an increase in ERP amplitude while others report a decrease in amplitude.

While measuring the amplitude of the P3a in older adults did yield important information for understanding cognition, other EEG components can be just as informative. Future studies might examine the latency of the P3a because it may provide significant information on the effects of cognition and training. Although latency has not been addressed much in this study, it can be a key factor in identifying perceptual and cognitive gains. Latency is the time at which the peak occurs, for example, the P3a typically peaks around 300 ms (Key et al., 2005). However, this time can vary by a couple hundred ms. Latency in the P300 component has been used to show how long it takes to detect and evaluate a stimulus, with shorter latencies showing increased cognitive performance (Polich, 2007). After seeing the effects of LACE training on P3a amplitude, it would be interesting to see if the latency of the P3a was affected as well.

Future studies may also look into the amplitude of the N2 component as well. The N2 peak is typically elicited by response inhibition, commonly seen with a Go No/Go task (Key et al., 2005). In association with the current study, this could be used to measure older adults’ ability to inhibit useless distractor sounds while trying to focus their attention on the AB paradigm target sounds. It might also be worth looking at the MMN component. In auditory stimuli, the MMN can be invoked by any stimuli that is different from the normal and is thought to be representative of early preattentative memory, such as in echoic memory (Key et al., 2005). This could give insight into the early attention and how it changes after training.

The ultimate goal of cognitive training studies is to see if the effects from training will transfer over to aspects in daily life. Although this study did not specifically test the effects from training in daily living situations, results suggest that older adults may benefit from the training for everyday cognitive performance. For example, improvements in the rapid recognition of words and sounds among distracting sounds may help individuals with their performance while driving. As previously mentioned, the loss of driving can lead to mental as well as physiological decline in older adults (Edwards et al., 2009; Fonda et al., 2001). Recognizing sounds from potential harmful situations could improve driving ability and increase the time an older adult driver has on the road. Results from this study and others that use similar methods can be used to better understand attention and cognition and to build a foundation from which future cognitive training programs are informed. Although further research must be conducted to explore the transferability of these results to the daily lives of older adults, the current study has shown support for the potential of cognitive training's ability to reduce age related cognitive decline.

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Appendix

Word List for T2 in the AB Paradigm

AIR
ALL
ART
BEEF
BOOK
COOK
CRY
DAY
DEAF
DIME
DITCH
DOOR
EAR
EARTH
EAST
END
FIST
GO
GOOD
HALF
HIT
ILL
KEY
LOCK
LOOK
NEAT
NEW
NONE
OWL
RIP
ROT
TAPE
TOOL
TOY
UP
WALK
WHAT
WHIP
WHITE
WHO