LIFESPAN DIFFERENCES IN STRATEGY TRAINING BENEFITS: AN INVESTIGATION OF THE THETA AND ALPHA FREQUENCY BANDS

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2010

To my Mom, who has never lost faith in me

ACKNOWLEDGMENTS

I would like to thank the many research assistants and colleagues who assisted in all aspects of research development, execution and analysis. A special thank you to my advisor, Dr. William Keith Berg, who helped me along the way in both academia and life; it couldn't have been done without him. Teri DeLucca, my lab mate and best friend is a shining star and a true example of what a friend should be. To my sweet and very patient husband, you have inspired me to be a better person. Your tranquility and strength carried me to the end; and after all these long months of waiting, I'm back.

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May 2010

Chair: William Keith Berg
Co-Chair: Andreas Keil
Major: Psychology

Extensive research on the long-lasting and beneficial effects of strategy training has demonstrated its importance in real-world application. While little work has been done to investigate the physiological changes following strategy training, the results are promising. To further this work, younger and older adults were given strategy training on a difficult planning task (The Tower of London) while EEG was recorded. Both younger and older adults showed better performance following strategy training on directly trained problems as well as demonstrating transfer effects to other problems of a similar structure. Only younger adults were found to improve on problems where the strategy could not be applied, demonstrating the older adults' reliance on strategy training for cognitive improvement. Frontal theta activity was found to increase following training, replicating previous research that showed an increase in task-relevant regions of the brain following strategy training. Older adults were found to have larger increases than younger adults in frontal theta; a surprising but encouraging developmental difference. The alpha frequency band was found to be functionally relevant to the task in both the younger and older adults, showing similar increases in the frontal regions in the post-

training condition. The strategy training was found to both increase behavioral performance and differentially affect the theta and lower alpha frequency bands. Theoretical implications of the theta and alpha frequency bands are discussed in terms of their functional use during problem solving and how this changes across the lifespan.

CHAPTER 1
INTRODUCTION

Across the human lifespan, there is a prolonged transition of advanced cognitive functions: a gradual onset of these throughout the childhood and teen years followed by a decline of these same functions starting in middle age (De Luca, Wood, Anderson, Buchanan, Proffitt, Mahony, & Patelis, 2003). The decline of these functions has been attributed to the shrinkage of the prefrontal cortex, a region thought to handle executive functioning/working memory tasks (Rypma & D'Esposito, 2000). Older adults who perform poorly on these tasks consistently show altered brain activation patterns which may be indicative of a breakdown of the neural components underlying these important functions (Rypma et al., 2000). While this decrease in cognitive function may be inevitable, there is a considerable amount of work demonstrating the benefits of cognitive training for the elderly in compensating for all or some of this loss (e.g. Friedman et al., 1998; Riis et al., 2008; Verhaeghen, Marcoen, & Goosens, 1992). The current study aims to further the understanding of older adult cognitive plasticity through a training paradigm on a difficult planning/working memory task. Brain activity will be collected before and after training to understand the neural differences associated with aging and strategy acquisition.

Changes in Cognition and Across the Lifespan

The complex set of cognitive processes known as executive functions are thought to include the components of planning, working memory, inhibition and cognitive flexibility (Berg & Byrd, 2002; De Luca et al., 2003; Welsh, Pennington & Groisser, 1991). These processes are believed to be controlled in large part by the prefrontal lobes (Welsh et al., 1991). Of the various executive functions, one of the most complex is planning. Planning is considered to be a high-level cognitive component and involves actions such as goal-oriented behavior and strategy use (Berg & Byrd, 2002). Executive functioning abilities allow humans to succeed in a world of complex goals, plans and actions. A decline of these functions starting in the 5th decade of life can have serious consequences for the individual in terms of stability and independent living. Studies have shown a clear connection between the ability for independent living and executive functioning skills (Cahn-Weiner, Boyle, & Malloy, 2002; Grigsby, Kaye, Baxter, Shetterly, & Hamman, 1998). Typically, many aspects of executive functioning decline across the lifespan which can leave an aging individual without the necessary components for successful living. With a better understanding of this executive function decline we may be able to elucidate the necessary steps to take to slow down or remediate this inevitable regression of cognitive skills.

Working memory is considered one of the fundamental components of executive functioning; without it one could not remember goals or take action to complete them, making it an essential aspect of executive functioning. Working memory involves holding information in the mind and updating the currently stored information with new, more relevant information (Baddley, 1992). This ability is imperative for independent living; thus understanding its functional decline across the lifespan is inarguably worth further investigation and understanding.

De Luca and colleagues (2003) have carried out an important and comprehensive study of executive skills across the lifespan in participants ages 8 to 64. A battery of neuropsychological tests was administered including working memory and planning. Working memory was assessed using a task in which participants searched through an increasing number of boxes to locate a hidden coin (trials contain 3 to 8 boxes). For successful completion of the task, participants must not return to a previously explored box, resulting in increased difficulty level with an increased number of boxes. The easier levels (in which the participant only needed to search either 3 to 4 boxes) resulted in all age groups having similar performance in completing the task. Only on the more difficult trials (in which participants had to search through 6 to 8 boxes) did age-related differences emerge. On these trials, older adults scored lower on a composite strategy score derived from task performance as compared to younger adults. Mastery of less difficult levels in the older adult group demonstrates an understanding of the task rules and at least a general strategy for completing the task. During the most difficult levels of the task, the participant must fully engage their cognitive skills in order to be successful. It is possible that older adults were having difficulty in managing these more difficult levels because of a break down in cognitive skills needed to complete these more difficult tasks. While older adults possess the ability for lower functioning skills they are taxed during the more difficult levels of the task. It is important to understand what cognitive functions and abilities are related to this difference in performance.

Planning ability is another critical aspect of executive functioning and also declines with age (Zook, Welsh, & Ewing, 2006). Planning involves an individual making goal-oriented actions and achieving them through thoughtful, and often strategically calculated moves. Decline of this function has been thought to begin around the age of 60 (Daigneault & Braun, 1993). A popular task used to assess planning is the Tower of London. This task involves participants moving balls on one board to match the color and orientation of balls on a “goal” board. Completing the task successfully involves participants making goal-oriented moves and applying a strategy for executing the most appropriate moves for completion. The board contains three pegs and three balls which must be manipulated on the participant's board to match that of the goal board. Increasing the number of moves required to match the goal board has been shown to increase difficulty in completing the task (Berg, Byrd, McNamara, and Case, 2010). As was found in the working memory task, older participants are able to successfully complete easier planning problems (De Luca et. al, 2003). Performance on the easier problems did not differ across age group with only the hardest difficulty level showing older adults performing worse on both measures of task performance (number of perfectly solved problems and number of problems solved in maximum moves allowed; De Luca et al, 2003). A similar planning task, The Tower of Hanoi, has shown this pattern as well (Brennan, Welsh, & Fisher, 1997).

It has been suggested that this drop in optimal cognitive performance is due to the inability of older subjects to constrain their attention to the most task-relevant features. This ability, denoted as cognitive control, has been found to decline across the lifespan (Persson, Lustig, Nelson, & Reuter-Lorenz, 2007). A lack of additional cognitive resources would result in a decline or lack of cognitive control needed to successfully complete the task. If older adults are unable to maintain cognitive control during a cognitive task, interference could not be reduced and would result in poorer performance on the task. This concept is useful in explaining why older adults are able to complete more simple cognition but struggle with more difficult concepts and tasks.

Neuroimaging work has demonstrated differential activation patterns of younger and older adults on tasks which require different levels of cognitive control (Persson et al., 2007). On the low-demand task younger and older adults demonstrated similar activation patterns. On the high-demand task, however, older adults do not show as much of an increase in activation as the younger adults. It is suggested that cognitive control is handled by the anterior cingulated cortex, a region known to be impaired in older adults (Band & Kok, 2000). Electrophysiological work has replicated the findings of decreased activity in the older adult population during high-demand tasks, again suggesting an age-related dysfunction in this cognitive ability (West & Moore, 2005).

Changes in Brain Function Across the Lifespan

Underlying the behavioral postulations of older adult cognitive decline is the consistent evidence of neural breakdown of regions thought to handle the processing of executive functioning tasks. Various methods have shown that older adults have decreases in frontal lobe white and gray matter, decreases in dopamine, and changes in fMRI BOLD and PET signals (Venkatraman et al., 2010; Brennan et al.,, 1997; Pradham, 1980; Gunning-Dixon & Raz, 2003; Davis, Dennis, Buchler, White, Madden, & Cabeza, 2009). This neural breakdown has been correlated with the decrease in performance on executive functioning tasks (Raz, Dixon, Williamson, & Acker, 2002).

Research on working memory has implicated the frontal regions, particularly the dorso-lateral prefrontal cortex (DLPFC), as the main region underlying working memory processes (see Wager and Smith (2003) for a comprehensive meta-analysis). This frontal region has also been implicated in contributing to planning ability, strategy application and goal orientation (Wagner, Koch, Reichenbach, Sauer, & Schlösser, 2006; Anderson, Albert & Fincham, 2005; Fincham, Carter, van Veen, Stenger & Anderson, 2002). In a study of healthy young adults, participants completed multiple trials of the Tower of London, and showed heightened activity in the DLPFC and other regions known to be important in executive functioning abilities (e.g. anterior cingulate cortex; Lazeron, Rombouts, Machielsen, Scheltens, Witter, Uylings, et al., 2000).

Additionally the DLPFC has been implicated as being particularly susceptible to aging (Romine & Reynold 2005). During memory tasks, older adult fMRI BOLD responses are consistently smaller than younger adults, particularly in the DLPFC (Rypma et al., 2000). In a series of studies, Rypma and colleagues have demonstrated that the DLPFC is specifically affected by aging (Rypma, Berger, Genova, Rebbechi, & D'Esposito, 2005; Rypma, Prabhakaran, Desmond, & Gabrieli, 2001; Rypma et al., 2000). Participants were presented with a string of letters (varying from 1 to 8 letters) and told to hold those letters in mind for a certain period of time (5-12 seconds, depending on the study). After this delay period, participants were presented with a letter and asked if this letter was in the string of letters presented. Behavioral performance showed a decline in performance with increasing string lengths for both age groups. Both the ventro-medial prefrontal cortex and DLPFC were active during the task in both age groups, though only the DLPFC was found to have decreases in activation in the older compared to younger adult groups. While portions of the frontal regions seemed to be spared by aging, the DLPFC demonstrates declines in both function and structure (Bae, MacFall, Krishnan, Payne, Steffens, & Taylor, 2006).

While the above mentioned literature reveals the decline of activity in important brain regions across the lifespan, there is evidence to suggest that high-performing older adults may engage compensatory neural mechanisms during difficult cognitive tasks. Correlation analyses have demonstrated differential activation patterns in the DLPFC across the lifespan. Rypma and colleagues (2005) showed that younger adults who performed better on the task (faster reaction time) showed *decreased* DLPFC activation as compared to slower younger adults. For older adults this pattern was opposite; the high performing older adults (faster reaction time) showed *increased* DLPFC activity as compared to the slower older adults. This result suggested that the younger adults demonstrated better performance because of a higher working memory capacity, and thus needed fewer neural resources to complete the task. Older adults, on the other hand, had worse behavioral performance because of a low working memory capacity (or possibly a lack of cognitive control) and thus needed to recruit additional neural resources in order to perform as well as the younger adults. These high-performing older adults have adapted a method of neural compensatory activity which aides in the completion of difficult working memory tasks.

This compensatory activity has also been demonstrated in the Hemispheric Asymmetry Reduction in Older Adults model (HAROLD; Cabeza, Anderson, Locantore, & McIntosh, 2002). Research concerning this theory has shown that high-performing older adults have bilateral activation during cognitive tasks, while younger adults show more lateralized activity (Rajah & McIntosh, 2008; Lee, Leung, Fox, Gao, & Chang, 2008; Cabeza, 2002). This finding indicates that older adults are recruiting additional areas to aid in task performance. The increase in activation is thought to be compensatory since those older adults who recruited bilateral regions showed better performance on memory tasks as compared to other older adults who had more lateralized activity (Cabeza et al., 2002).

Improving Working Memory in Younger and Older Adults

Given the large amount of literature documenting the decline of cognitive functions across the lifespan, it is not surprising that researchers are striving to understand how to improve this. A plethora of research has found positive effects of training for older adults, demonstrating the plasticity of the brain in the later stages of life (Becic et al., 2008; Bottiroli, Cavallini, & Vecchi, 2007; Carretii, Borella, & Beni, 2007; Cavallini et al., 2003; Rapp, Brenes, & Marsh, 2002; McNamara & Scott, 2001). The variety of research in this area has led to some general conclusions about memory training enhancements and its age-differentiated effects across the lifespan. First, older adults have the ability to increase memory performance, demonstrating a continued plasticity of these functions for cognitive learning (Singer et al., 2003). Intensive cognitive training has been found to improve performance in older adults in a myriad of cognitive domains (Sensory and cognitive training: Mahncke, Connor, Appelman, Ahsanuddin, Hardy, & Wood, et al., 2006; Visual search training: Becic, Boot, & Kramer, 2008; Ecologically valid tasks: Cavallini, Pagnin, & Vecchi, 2003; Speed of processing: Edwards, Wadley, Myers, Roenker, Cissell, & Ball, 2002; Working memory: Dahlin, Nyberg, Bäckman, & Neely, 2008). Training paradigms implemented with the oldest-old (over 75 years old to 101 years old) have also demonstrated benefits through intensive training (Singer, Lindenberger, & Baltes, 2003; Yang & Krampe, 2009). This continued plasticity, even into the latest phases of life, shows the importance and value of this technique.

A second important finding from these studies is the ability of these effects to be sustained over time. If the effects from training last only for a short time, this greatly diminishes its importance for changing the life of an older adult. But in a comprehensive study of the duration of memory training effects, training-induced improvements were still found at a 2 year follow-up in both the younger and older adults (Ball, Berch, Helmers, Jobe, Leveck, & Marsiske et al., 2002). This finding has been replicated in other research, using more ecologically valid tasks (Bottiroli et al., 2007).

A critically important aspect of memory training is whether that training can and will be of benefit in circumstances beyond those specifically trained. This cognitive process, termed ‘transfer of training’, is important because it demonstrates that the participant is not only applying the procedure originally learned to the type of problem specifically trained, but can also generalize that knowledge to a similar or dissimilar problem or task. If the participant can transfer the knowledge to a different problem or task, it can be suggested that they understand the procedure or strategy involved and are not just “going through the motions.” Six levels of transfer have been outlined by Haskell (2001), ranging from simple learning and application (Levels 1,2 and 3) to more advanced transfer of training (Levels 4, 5 and 6). The more advanced levels are thought to evidence a true transfer of the learned strategy to a new situation. The main types of transfer studied in the aging literature are Near and Far transfer (Levels 4 and 5, respectively). Near transfer occurs when there is a transfer of previous knowledge to a new situations which is similar to the original situation. Far transfer occurs when there is a transfer of previous knowledge to a new situation which is not similar to the original situation. Near transfer would be if a participant were to be trained on a working memory task and were able to apply that learning to a different type of working memory task. Far transfer would be the ability to transfer the learning from the working memory task to a planning task. The terms “direct” and “indirect” are applied here, though these terms are analogous with the more popular terms “near” and “far”. These terms are applied as the methodology employed in this study are better describes as direct and indirect as compared to near and far.

Younger adults have generally shown consistent transfer of strategies to problems similar to those trained, known as direct transfer problems (Li, Schmiedek, Huxhold, Röcke, Smith, & Lindenberger, 2008; McArdle & Prindle, 2008; Wright, Thompson, Gains, Newcombe, & Kosslyn, 2008), but show less consistent transfer to less related problems, known as indirect transfer problems (Dahlin et al., 2008; McArdle et al., 2008; for a review, see Rebok, Carlson, & Langbaum, 2007).

Older adults often do not show transfer on the indirect problems, which concerns researchers that laboratory-based memory training will not affect non-related tasks (Rebok et al., 2007; Ball et al., 2003). In a comprehensive study of the transfer of working memory training to indirect and direct tasks, younger and older adults were trained on a spatial working memory task over several weeks (Li et al., 2007). The trained task, the spatial n-back, taps updating working memory by requiring participants to indicate a match between the current stimuli and two stimuli previously presented (2-back). To measure the effect of transfer to similar (direct) and closely related tasks (indirect), two direct transfer tasks and one indirect transfer task were given to younger and older adults after training in the spatial working memory task. Performance on these tasks was compared to a comparable group on non-trained younger and older adults. The first direct transfer task, a harder version of the spatial n-back task (3-back) showed better performance in the trained as compared to non-trained younger and older adults. However, this type of direct transfer only demonstrates that participants increased in a specific skill and not a generalized gain of knowledge. The second direct transfer task was a 2-back working memory task which utilized different stimuli though required the same cognitive skills for completion. Again, both age groups that were trained successfully completed this task better as compared to the non-trained group. This shows that the training was able to be transferred to a task using similar cognitive processes but different enough to demonstrate that the cognitive training was effective in aiding performance on this task. The two indirect transfer tasks included tapping cognitive skills related to but not completely reliant on working memory. These tasks required participants to use complex memory span, a construct that is not directly related to updating of working memory though can be argued to be in the same family of cognitive functions. In both of these tasks, the non-trained and trained participants did not differ in their performance. Training on the spatial working memory task did not improve performance on a different type of working memory task in either the younger or older adults. The lack of transfer to indirect tasks has been mirrored in other studies as well. In a large study of adult memory training, older adults trained in several cognitive skills did not demonstrate improvements in everyday memory tasks (Ball et al., 2003). One area of research that has been able to demonstrate transfer effects is training in processing speed (Ball, Edwards, & Ross, 2007). It is suggested that cognitive slowing is an important factor in cognitive decline across the lifespan (Zimprich & Martin, 2002) making the impact of processing speed training understandable. In a meta-analysis of 6 studies which employed speed of processing training, it was found that age, education and mental status did not impact the level of improvement from training (Ball et al., 2007). The only factor which showed significant relation to the improvement due to speed of processing training was the initial speed of processing performance of the participant. Those with the lowest scores on the speed of processing test at the initial baseline showed the largest levels of improvement. This indicates that this group of participants greatly benefits from the training, and the construct of speed of processing is an important factor when measuring performance gains across the lifespan.

The importance of speed of processing in cognitive functions has been demonstrated in many cognitive paradigms (for a review, see Salthouse, 2005). Since processing speed is defined as the speed with which different cognitive operations can be executed it stands to reason that increases in this ability would aid skill acquisition (Reichenberg & Harvey, 2007). Additionally, the task has been associated with working memory functions as those participants who are able to remember the pairing would complete more pairs (Koziol & Budding, 2009). Older adults have been found to have consistently poorer behavior on this task compared to younger adults. While this test clearly measures processing speed, the impact of speed of writing may also play a role; the age difference relating to a slower motor ability rather than a cognitive one (Joy, Kaplan & Fein, 2004). It is likely though that both cognitive and motor slowing impact the performance on this task. In an adapted version of the digit symbol task, younger and older adults completed the task during fMRI scanning (Venkatraman et al., 2010). Both younger and older adults showed bilateral frontal activation and left parietal activation, regions both associated with working memory/executive control. Additionally, activation in these regions was associated with better performance and fewer structural abnormalities, as measured by white matter tracks across the brain (gained from the measure of diffusion tensor imaging). This suggests that completion of this task relies heavily on brain regions active in cognitive, rather than just motor abilities.

Older adults have been found to have poorer performance pre-training, and have fewer gains from training, as compared to younger adults (Verhaeghen & Marcoen, 1996). This finding is possibly due to the ineffective strategy application of older adults on cognitive tasks. Brigham and Pressley (1988) demonstrated this by teaching all participants two strategies; one which was an effective process for completing the task and a less effective strategy. The task, learning a list of vocabulary words, was administered to younger and older adults before and after the strategy training. All participants received training on both types of strategies. All but one younger adult (out of an *n* of 30) was able to tell which strategy was superior and employ that strategy. The older adults did not successfully choose the effective strategy and could not tell which strategy was more effective. Poor strategy choice in the older adult group indicated a reduced meta-cognitive awareness of the differences in strategy application. This same finding has also been replicated in more recent work (Lamson & Rogers, 2008; Yagoubi, Lemaire & Besson, 2005). In this light, it may be that older adults are struggling with working memory tasks, and executive tasks in general, because of a poor strategy choice. When older adults are taught a relevant strategy their performance increases dramatically because they are now exposed to the correct way of solving the task. This was demonstrated in a study which older adults who chose the wrong strategy were trained to choose more optimal strategies (Becic et al., 2008). Performance was substantially improved in the older adults who were given strategy choice training, demonstrating that older adults are capable of completing these tasks when shown the most optimal strategy.

Physiological Changes Accompanying Working Memory Training

Studies of physiological changes after training have consistently shown increases in activation of task-relevant areas in the post-training condition (Olesen, Westerberg, and Klingberg, 2004). In a series of studies, Klingberg and colleagues had younger adults complete an intensive training period; fMRI activity was measured before and after training (Westerberg and Klingberg, 2007; Olesen et al., 2004). Training included repetitive presentation of a spatial working memory task which was adapted to the participant's level of achievement. As the participant improved on the task, it became increasingly more difficult, which allowed the participant to improve their working memory capacity. Analyses investigated the changes in activity from the pre- to post-training condition. The pattern of activity was similar in the pre- and post-training condition, though the post-training condition showed significantly higher levels of activation as compared to the pre-training condition. Thus, there were no additional areas of activation in the post-training condition, only an increase in previously activated regions.

Physiological measures can also highlight differences in activation patterns across the lifespan (Rosano, Aizenstein, Cochran, Saxton, de Kosky, Newman et al., 2005). Brain activity measured before and after strategy training may indicate differential patterns of activation across the lifespan, highlighting developmental differences not apparent in behavioral research. The Method of Loci (M.O.L) training is beneficial to both younger and older participants, as demonstrated in numerous behavioral studies employing this methodology (Becic et al., 2008; Bottiroli et al., 2007; Carretii et al., 2007; Cavallini et al., 2003; Rapp et al., 2002; McNamara et al., 2001). This technique has participants associate imagined places (*loci*) along a walk with the stimuli to be remembered. The participant is then able to memorize the stimuli by associating them with more familiar stimuli. Nyberg and colleagues (Nyberg et al., 2003) trained younger and older adults in M.O.L, collecting PET images before and after training. The post-test condition showed increased activation of task-relevant regions in all participants. Behaviorally, participants were divided into three sub-groups. The first group was the younger adults, all showing substantial improvement on the behavioral task in the post-training condition and showing the best performance in comparison to the other groups. The older adult age group was then segmented into older adults who benefited from the strategy (Old +) and those who did not (Old -). While in the pre-training condition the Old + and Old - did not differ in regions or strength of activation, several post-training differences emerged. The Young and Old + adults showed increased activity in the parietal/occipital regions, areas known to be active during this type of task (Cabeza & Nyberg, 2000). This is in contrast to the Old - group who did not show any increases in parietal/occipital activation in the post-training session. Thus, though the Old + performed worse on the task as compared to the younger adults, their pattern of task-relevant brain activation was similar. The Old + group was successfully employing the strategy, which was demonstrated both behaviorally and physiologically. The Old - group, on the other hand, did not demonstrate strategy application and showed differential activation patterns as compared to the Old +.

A recent study aimed at training older adults in cognitive control demonstrated that training based on this construct is both possible and beneficial (Braver, Paxton, Locke, and Barch, 2009). Older adults were trained to the strategy of attending to the cue stimuli rather than the target stimuli for a continuous performance task. Behavioral data demonstrated an increase in cue-focused behavior and evidence of increased cognitive control. Activation of the prefrontal cortex (PFC) was found to have increased in the second session, and this increase was related to performance on the task. Better performance on the post-training task was associated with higher activation in regions of the PFC. These training studies have demonstrated that while older adults may show worse behavioral performance as compared to younger adults, they are activating many of the same brain regions.

Why Do We See Varying Changes in Task Relevant Brain Activation After Training?

As noted above, physiological changes after strategy training result in an increase in the task-relevant brain regions. Studies of motor strategy training have shed light onto the different phases of strategy acquisition and implementation that occur as training proceeds. When a participant is taught a motor strategy on a task there are several stages of acquisition and implementation that are required prior to mastery of the learned strategy (Doyan and Benali, 2005). During the first stage of motor strategy application, participants are bringing new processes online for task completion that were not previously employed. This first stage is reflected by an increase in activity in task-relevant regions during this time. Later phases of motor strategy application, in which participants may be consolidating information, are denoted by continual decreases in activation. This is thought to represent an increased efficiency in neural processing and thus a decreased need for neural resources. If this same theoretical framework is applied to cognitively-based strategy application, the participants in the studies described would still be in the first phase of strategy application. This is possible for two reasons. Firstly, most of the studies looking at physiological changes after training are single-session testing paradigms (e.g. Nyberg et al., 2003), and even those that have extensive practice do not test the participant on the task for more than one session (e.g. Westerberg et al., 2007). Secondly, it is feasible that cognitive tasks may require more practice to become automated as compared to motor tasks which can have simpler demands. As such, it might be expected that post-training physiological signatures would show increased activation in the initial post-training phase as compared to the pre-training phase.

The Use of Electroencephalogram Activity in the Study of Human Cognition

While the literature discussed above has relied on fMRI techniques to distinguish regions of activation across training sessions, other physiological techniques may also be useful. To date, my careful review has not been able to locate any studies of training investigating the changes in electroencephalogram (EEG) signatures pre- to post-training. The use of this method can provide additional information that is lacking in the previously conducted research. Of most importance is the temporal resolution afforded to EEG that is lacking in fMRI. It is likely that there are different regions of activation immediately following the presentation of the strategy (as in the first several seconds after the strategy is being explored) as compared to later in the trial when the strategy is more actively applied. While fMRI analysis is typically done by collapsing the BOLD signal across a trial or several trials, EEG signatures can be examined in millisecond accuracy to understand fluctuations in power and topography as the early process of strategy analysis, the subsequent exploration and evaluation, and later strategy development and application unfold. This technique is especially useful in cognitive paradigms that study long-lasting processes, such as planning and problem solving.

In order to understand the complex EEG data collected during the task, researchers have employed various data reduction analyses. The statistical procedure often used to extract frequency information from the EEG is a Fast-Fourier transform (FFT). This method gives a measure of power in each of the frequency bands associated with traditional EEG analyses, such as delta (2-4hz), theta (4-7hz) and alpha (8-12hz), etc. It allows the investigator to understand how the power of each frequency changes across independent variables. For example, Sauseng and colleagues (Sauseng, Klimesch, Doppelmayr, Hanslmayr, Schabus & Gruber, 2004) found that activity in the theta frequency band increases with an increase in task difficulty level. They report that increases in theta power indicates that more resources are being put towards the task now that it is more difficult for the participant.

Theta Changes in Power Across the Lifespan

Theta power has been shown to increase during cognitive tasks, a sign that this frequency band is an appropriate indicator of mental effort. Young adults performing a serial letter task (Sternberg task) showed marked increases in theta power in the frontal regions (Onton et al., 2005). Increases in memory load (0-5 letters) and the maintenance period (2-4 seconds) resulted in significant increases in theta power. Regions in the frontal cortex (frontal midline theta, discussed below) showed progressive increases in theta power with increasing difficulty level. Other regions of interest did not show comparative theta increases, demonstrating this is specific to the frontal regions for task manipulation. Increases in theta power related to increases in the maintenance period demonstrate that theta power is not only linked to a number of stimuli but also to mental effort. In support of this finding, several working memory paradigms have also demonstrated increases in theta power during cognitive tasks (Ragavachari, Lisman, Tully, Madsen, Bromfield, & Kahana, 2005; Mizuhara, Wang, Kobayashi, & Yamaguchi, 2004; Sauseng, et al., 2004; Grunwald, Weiss, Krause, Beyer, Rost, & Gutberlet et al., 1999).

As noted, the frontal theta power has been found to be concentrated in the frontal midline (FM) region under higher task demands. Researchers have thus termed this frontal theta power as FM-theta. As discussed above, frontal theta was correlated to increases in memory load. When the impact of the FM-theta was statistically removed from the signal, a correlation of task load to theta power was no longer significant. This confirms that the association of theta power with mental effort is concentrated in the frontal midline region. Source localization of the FM-theta suggests the cortical generator is the anterior cingulate cortex (ACC) (Onton et al., 2005; Gevins et al., 1997). The ACC has been implicated in attentional systems and significant cognitive effort, so its involvement in frontal midline theta is reasonable.

Frontal midline theta has also been found to increase with increased practice and strategy application on a task (Gevins, Smith, McEvoy & Yu, 1997; Smith, McEvoy, & Gevins, 1999). Participants completing the n-back task demonstrated increases in FM-theta during the task, and increases during more difficult levels of the task. Interestingly, FM-theta was higher in the last blocks of trials as compared to the first block of trials. It is suggested by Gevins and co-authors that this increase in FM-theta is due to increased mental effort on the task with more advanced strategy usage. As with the fMRI training literature, FM-theta demonstrates an increase in activity after practice.

This suggests that FM-theta is an appropriate tool for investigating physiological changes due to strategy training.

Several studies have found decreased power in frontal midline region in older adults (Cummins & Finnigan, 2007; McEvoy, Pellouchoud, Smith & Gevins, 2001). During a working memory task (n-back), both younger and middle aged adults demonstrated increases in FM-theta with increasing difficulty level. The older participants, however, did not show an increase in FM-theta during increased task difficulty, which is thought to be indicative of a breakdown of processing mechanisms in the frontal regions.

This result has been replicated in other studies of older adult FM-theta. During a modified Sternberg task (in which the memorized set was words rather than letters), older adults showed lower FM-theta levels as compared to younger adults in both the retention and recognition intervals of this task (Cummins et al., 2007; Karrasch, Laine, Rapinoja, & Krause, 2004). Results again suggest disruption in the frontal regions in older adult groups. Based on these two studies, many further questions can be asked. Is the decrease in FM-theta due to age related changes in brain structure or possibly due to differences in task performance and mental effort? As suggested by the training literature, one would expect an increase in FM-theta with increased mental effort and strategy application. Further investigations of FM-theta and its changes in strategy training may answer some questions about its underlying functional significance to cognitive tasks.

While there is currently no work investigating the differences in theta power before and after training, it is expected that this change will follow suit with the fMRI research (e.g. Nyberg et al., 2003). Frontal midline theta was been found to increase in power with increased exposure and practice on a task (Gevins, et al., 1997). Younger adults performed a spatial n-back task, with varying difficulty levels, over a prolonged period of time. In addition to demonstrating increases in theta power with increased difficulty of the task, practice effects were also investigated. Comparison of frontal midline theta between the first and last block of problems showed a clear increase in power with increased practice. Interestingly this interacted with difficulty level with larger increases in theta power with practice for more difficult problems. The authors infer that this is related to task performance and the increasing demands and difficulty of maintaining attention on this task for an extended period of time. Clearly, frontal midline theta is an appropriate tool to study developmental changes in strategy application due to its sensitivity to age, difficulty level and practice effects.

Alpha Changes in Power Across the Lifespan

Although it has been postulated in the past that the function of alpha was solely for periods of inactivity or "brain idling" (Jensen, Gelfand, Kounious & Lisman, 2002), more recent research has begun to uncover a very different picture of what alpha brain activity may represent. Contrary to the notion that alpha activity represents a relatively inactive brain, several studies have shown increases in alpha activity during cognitive tasks (Sauseng, Klimesch, Schabus, et al., 2005; Sauseng, Klimesch, Stadler, et al., 2005; Silberstein, Danieli & Nunez, 2003; Jensen, et al., 2002), and this increase has been associated with better performance (Hoptman & Davidson, 1998). The alpha frequency band has been divided and designated as lower (8-10hz) and upper (11-13hz) alpha frequency bands.

The lower alpha frequency band has been associated with changes in cognitive tasks and found to be generated in the frontal and parietal regions (McEvoy, et al., 2001; Gevins et al., 1997; Klimesch, Schimke, & Pfurtscheller, 1993). Younger adults completing a difficult working memory task showed clear increases in the lower alpha frequency band during the task as compared to the rest condition (Gevins et al., 1997).

The upper alpha frequency band has been associated with basic visual processing by some researchers (McEvoy et al., 2001; Gevins & Smith, 2000) though it has also been attributed to being involved in long-term memory processing (Klimesh, Freunberger, & Sauseng, 2009). When investigating power changes between task conditions, there seems to be little increase in the upper alpha frequency band (McEvoy et al., 2001). However, Klimesh and colleagues who have investigated the long range communication of this frequency band suggest a more cognitive role.

Klimesch and colleagues have developed a theoretical framework to suggest a functional role of the alpha frequency band which spans both lower and upper ranges. The Klimesch framework suggests that alpha is playing a functional role of long-range communication between frontal and parietal brain regions necessary to complete working memory tasks. Thus, the alpha band is no longer seen as an indication of idling, but as a possible index of functional relevance to certain tasks. This view would suggest an increase in alpha with increased mental effort similar to the function of the theta frequency band. However, other research would suggest a different functional role for the lower alpha band. Jensen and colleagues have shown an increase in lower alpha in non task-relevant regions suggesting alpha is inhibiting regions not necessary for task completion (Jensen et al., 2002). Clearly, the function of the alpha band is not fully understood. While the exact role of alpha is not well-defined, it clearly has a functional relationship with cognitive tasks. Further investigation into the alpha band will help to more fully understand its role in the completion of cognitive tasks.

Research in older adults investigating the lower and upper alpha frequency band have shown differential patterns of alpha activity across the lifespan (McEvoy et al., 2001). During an n-back task, younger adults showed increased deactivation of the lower alpha frequency band during task performance in both the frontal and parietal regions. This was interpreted as younger adults showing increased task engagement in these regions, following the more traditional view of alpha as a measure of cortical idling. Older adults were found to show decreases in only the parietal regions, without a decrease in the frontal regions. The upper alpha frequency band did not show clear changes across age or task epochs suggesting a less cognitive role. Clearly, this result could be interpreted several ways, depending on the applied theoretical model. Further investigation of what the lower and upper alpha bands may represent and its changing function across the lifespan is needed to interpret the presently available evidence.

Current Study

The study employs a working memory training technique on a difficult variant of a spatial planning task (the Tower of London) with younger and older adults, in order to understand the changes in behavior and physiology as a consequence of training. The Tower of London task offers several advantages over more commonly used training tasks. Firstly, the complexity of the task allows for large differences in performance, shedding light on factors important for individual ability to perform on the task and effects of the trained strategy. Secondly, while strategies employing more simplistic training techniques are widely present in the literature (e.g. MOL), little work has been done to understand complex strategies involving spatial manipulation (Li et al. ,2008). The Tower of London makes significant demands on working memory, allowing comparison of these results to previous working memory studies while adding new information to the current knowledge of strategy training across development (Phillips, Wynn, Gilhooly, Sala, & Logie, 1997). The Tower of London activates similar regions of the brain as do standard working memory tasks, such as the DLPFC, and incorporates regions known to handle spatial manipulation (e.g. the parietal lobe; Anderson et al., 2005). As discussed above, the developmental performance trajectory of the Tower of London has similar timing to working memory paradigms (De Luca et al., 2003). Thus, while this is the first study to employ strategy training with the Tower of London, the theoretical justification and application to previous work is clear.

Based on previous research, it is expected that initial performance on the TOL will be better in the younger age group as compared to the older age group. This will be shown by the younger adults showing more correct responses and faster solution times on the TOL. Training is expected to result in increased performance for younger and older adults, though previous research would suggest a greater benefit of training for the younger age group (Lustig, Shah, & Seidler, 2009). Investigations of theta power will be limited to the frontal and parietal regions to further explore the decrease in FM-theta in older age. It is expected that older adults will exhibit lower theta power as compared to younger adults, specifically in the FM-theta region (McEvoy et al., 2001; Cummins et al., 2007), with the older adults having a relatively smaller increase in theta in the post-training session as compared to the younger adults. Hemispheric differences in the frontal regions will be explored as this has been found to be important in TOL performance ability (Goethals, Audenaert, Jacobs, van der Wiele, Pyck & Ham, 2004; Morris, Ahmed, Syed, & Toone, 1993). Since the alpha band has not been found to have a unifying theoretical basis of change across age or task, exploratory analyses will concentrate on regions of interest that may shed more light on its functional importance in this cognitive task. The lower alpha frequency band will be investigated at the frontal and parietal sites, as interesting developmental differences were found in a cognitive task (McEvoy et al., 2001). The upper alpha frequency band will be investigated in the parietal regions, as it has been found to be maximal in this region (McEvoy et al., 2001; Gevins et al., 1997). And finally, the impact of individual variations in processing speed will be explored to assess its importance and impact on brain changes.

CHAPTER 2
METHODS

Participants

Participants were tested in a pre/post design, with all participants completing two sessions. The second session, spaced one to four days following the first session, included a strategy training program. All participants analyzed completed both sessions successfully, indicated they were right-handed, and use English as their primary language. All participants were asked of head trauma or neurological diseases likely to affect the brain (e.g. Parkinson's disease, stroke), in which all indicated they had not. The younger adult group (*n* = 32) was between the ages of 18 and 24 and recruited from the Gainesville, Florida area. Most younger adult participants (87%) were recruited from the general psychology course held at the University of Florida and received credit for their participation. The remainder of the young adult group was also recruited from Gainesville, Florida and had similar educational backgrounds. The older adult age group (*n* = 24) was between the ages of 63 and 79 and recruited from the Gainesville, Florida area. All older adults who participated in the study were deemed cognitively capable by the administration of the Telephone Interview for Cognitive Status (TICS; Folstein, Folstein, & McHugh, 1975). The TICS is an 11 question assessment of orientation, concentration, short-term memory and delayed recall done over the phone to screen participants for mild cognitive impairment. The use of the TICS as an assessment of cognitive status has been validated in comparison to more in-depth cognitive interviews demonstrating the clinical use of this tool for assessment of mental stability in an older adult population (Knopman, Roberts, Geda, Pankratz, Christianson, Petersen, et al., 2010; Duff, Beglinger, & Adams, 2009). In addition, the TICS has been found to be have similar diagnostic outcomes as compared to the Mini Mental State Examination (MMSE; Ferrucci, Del Lungo, Guralnik, Bandinelli, Benvenuti, Salani, et al., 1998). As suggested, in comparison to other more extensive tools of assessment, a cut-off score of 28 was used to screen out participants with cognitive deficits (Barber & Stott, 2004). Only one screened participant had a score of 28 but this person was excluded due to missing the second appointment.

Table 1 outlines the demographic information of the final N for this study. Of the ninety-one participants that were originally screened to participate in this study, fifty-six are included in the final N. The main reason for rejection for these participants was failure to return for the second appointment, found mostly in our younger subjects. The second most common reason for rejection of a participant was poor quality EEG. The term “poor quality EEG” is an umbrella for many problems which happened with the EEG including poor signal (n=2), too many motor artifacts in the data (n=12), and equipment failure (n=7). Only two participants were excluded due to experimenter error.

Table 2-1. Demographic and Neuropsychological Data of the Final Sample

	Age (st.dev)	Digit symbol Score (st.dev)	TICS Score (st.dev)	Percentage of Males	Percentage of Caucasian
Younger Adults	20.04 (1.64)	70.00 (8.41)	N/A	54%	74%
Older Adults	70.81 (4.55)	50.68 (11.75)	36.20 (2.77)	57%	91%

N = 56

Measures

Digit Symbol Task

To assess individual variations in processing speed, the digit symbol substitution task was administered during the first testing session (Wechsler Intelligence Scale for Adults - 4th Edition). This speeded task has participants completing pairs, based on presented stimuli to assess processing speed. The applicability of this task has been shown in models which indicate processing speed as an important predictor of strategy usage and memory performance (Verhaeghen and Marcoen, 1996). In this task, participants are shown the numbers 1-9 and their matched symbol (see Figure 2-1, block A for a fabricated example similar to that used in this test). During the test, participants must correctly write in the symbol below the number (Figure 2-1, block b). There are a total of 93 pairs to complete within a total time of 90 seconds. No participants were able to complete the entire board in the allotted time. The score on the digit symbol was derived by taking the number of correct responses minus the number of incorrect responses. Average performance on this task can be found in Table 1.

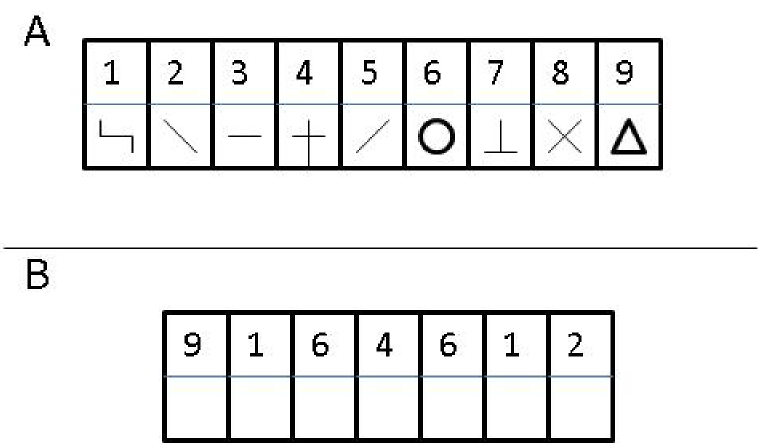

Figure 2-1. Digit/Symbol Task, a task of processing speed assessed during the pre-training session in both younger and older adults. (A) The legend of the test which tells participants the matching pairs, (B) The portion for the participant to fill in during testing.

Tower of London Planning Task

The TOL is a planning task in which participants are asked to manipulate the balls on the move board to match the balls in color and orientation to the goal board (See Figure 2-2). There are several rules to the TOL: only one ball can be moved at a time, balls must always be placed on a peg, and there a is maximum of three balls that can fit on the tall peg, two balls on the middle peg, and only one ball on the small peg.

A modified version of the TOL was administered to participants in which the participant was only able to view the picture of the move and goal boards, and was not able to actually manipulate the balls. In the typical version of the TOL, participants are able to move the balls on the move board to correctly match the ball configuration on the goal board. In this modified version, participants were asked to covertly manipulate ("in their heads") the balls into the correct order. This modified version has been successfully used in previous fMRI research (e.g., van den Heuvel, Groenewegen, Barkhof, Lazeron, van Dyck, and Veltman, 2003) and was employed here for several reasons. Firstly, the manual manipulation of the balls would create excess artifacts that could have rendered the EEG data useless. Secondly, this covert solution paradigm results in a substantial increase in the demand on working memory, including both the short-term storage and the manipulation aspects of working memory. Throughout the solution, participants must keep in mind what balls they have moved and where the current ball placements are. With this change in task presentation, the working memory strategy training can be expected to become far more critical.

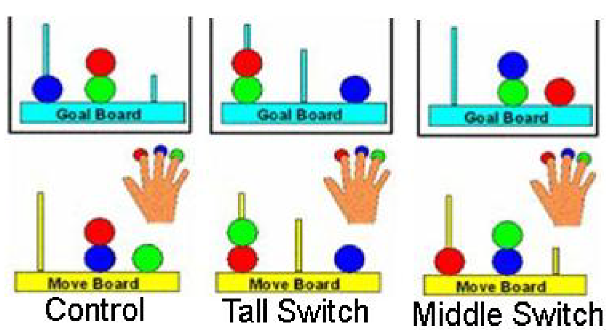

Figure 2-2. Three types of Tower of London Problems. Presented problems could either be categorized as switch (Tall or Middle) or control problems.

Participants were presented with 54 trials of the TOL during each session to adequately measure performance on this task before and after training. TOL difficulty level was measured by number of moves needed to complete the problem. Each problem required the participant to move five or six balls for correct completion. Number of moves has been used in the past as an indication of the difficulty of the problem (Berg et al., 2002). De Luca, et al. (2003) found that older adults struggled with 5-move problems, making this problem selection ideal with detection of strategy application.

During each TOL trial, a problem was presented for a maximum of 45 seconds. During this time participants attempted to solve the TOL problem covertly and, whenever ready, respond with the color of the last ball put into place using a simple keypad provided (see Figure 2-2). Using this response technique, a correct answer would indicate that the participant solved the problem in the fewest number of moves, or guessed the correct answer. Responding above chance level (33 percent) indicates that participants are solving the problems. If the participant did not respond within the allotted 45 seconds, they were automatically moved on to the next problem. Once the participant responded or the 45 second maximum was reached, there was a brief inter-trial interval of five seconds where the participant viewed a small red circle in the middle of the screen. After this rest period, the next problem was presented. Feedback on task performance was not provided during the testing procedure.

Selected problems for the Tower of London

Training of a selective application of the strategy to some, but not all, presented problems was accomplished by constraining the types of problems presented to participants. Two out of the three problem types presented allowed participants to either directly or indirectly apply the learned strategy. The other type of problem (control problems) could not be solved by applying the strategy and served as a control condition.

Switch Problems: Problems that were able to be solved by applying the trained strategy are identified as switch problems. These problems are characterized by having two balls on a single peg in opposite orientation for the goal and move board. For example, in Figure 2-2 middle panel, balls on the tall peg for the move board are ordered red-green (red on top, green on bottom) but are on the goal board as green-red. Since this opposite orientation is occurring on the tall peg, these are identified as tall switch problems. Those referenced as middle switch problems, shown in the right panel, are analogous with balls being reversed in order on the middle peg. Participants received training on only one type of problem, either tall or middle switch training. The training could then be applied directly to trained problems (e.g. tall switch training directly applied to all tall problems) or potentially transferred to assist in indirectly solving trained problems (e.g. tall switch training indirectly applied to middle switch problems).

Control Problems: These problems are identified by a lack of balls being in the switch orientation from the move to goal boards (Figure 2-2, left panel). Ball placement for these problems was selected based on the same number of moves required (five or six) as the switch problems. These problems were presented to effectively measure the effect of practice alone with the task rather than specific strategy training. The switch strategy could not be successfully applied to these problems, and thus any increase in performance on the second session would indicate general practice gains, not increase in performance due to strategy application.

The 54 problems presented per session were divided into 18 control, 18 middle switch, and 18 tall switch problems. Problems were presented in nine blocks, six problems per block. Each block contained two problems of each type (a list of presented problems can be found Appendix A) and order was pseudo-randomized within the block. Performance measures included proportion correct, solution time and proportion of no responses (not responding by the end of the 45 second interval).

Working memory strategy training

During strategy training, all practice problems and discussion of the application of the strategy were performed on either the tall or middle switch problems. No mention of the other type of switch problem was discussed during training. Participants were randomly selected into either the middle or tall switch training conditions. Training was presented in PowerPoint format on a screen sitting in front of the participant. First, training consisted of the participants being able to correctly recognize a switch problem. Once participants were able to complete this step, demonstration and application of the strategy is applied to 4-, 5- and 6-move switch problems with appropriate corrective feedback from the researcher provided as needed. No participants needed to complete the training more than one time.

During the first part of the training, participants were trained on the “basic sequence” for 4-move switch problems. As shown in Figure 2-3, this sequence involves four moves to correctly reverse the balls and solve a 4-move switch problem. Participants were trained on solving this type of problem two times and then given two chances to apply the strategy with corrective feedback as needed.

During the second part of the training, extensions of the basic strategy were demonstrated by building upon the basic sequence. Participants were taught three such extensions. These additional strategies are involved in solving the 5- and 6-move problems. For the 5-move problems, a ball can be moved prior to the switch taking place (Figure 2-4) or after the sequence has taken place (Figure 2-5) depending on the specific problem. Participants are trained to recognize when these additional moves are necessary and also given training on applying this extension to solving the problem. The researcher demonstrated each of these extensions two times, with the participant given two times in which to apply each extension while receiving corrective feedback as necessary. For the 6-move problems, an additional ball move is needed both prior to as well as after the basic sequence (Figure 2-6). As with the previous extension, participants are given the opportunity to see a demonstration and try an application of this technique. This ensures that all participants not only have a chance to see the board being solved but also to solve it on their own.

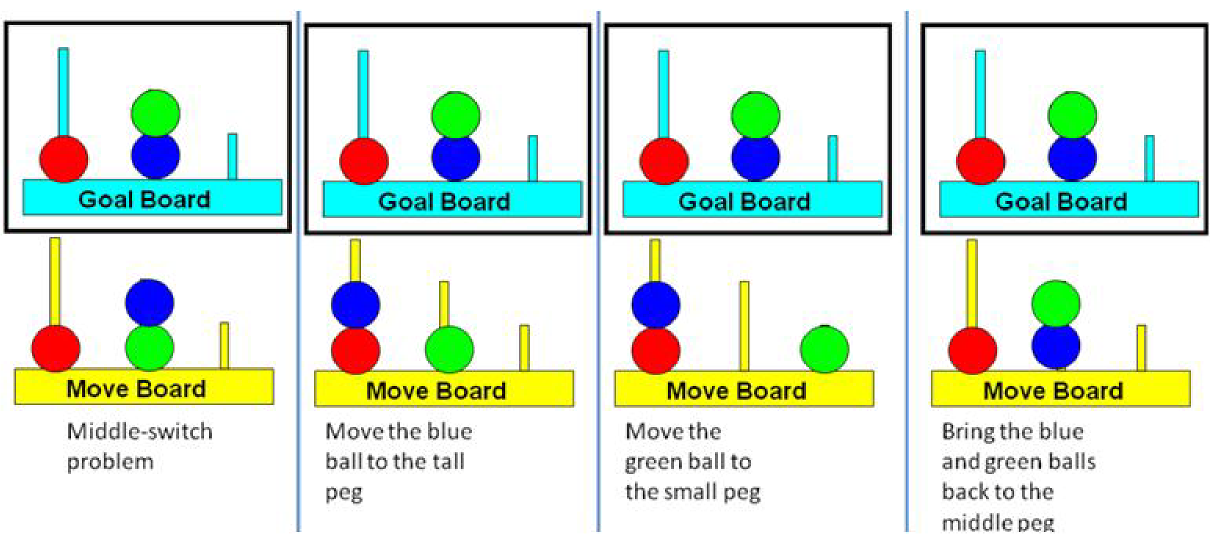

Figure 2-3. Depiction of Moves Needed for the Basic Strategy Sequence, Participants were first taught this strategy sequence and then trained on more advanced sequences.

The entire training session lasted an average of 20 minutes. In total, participants received four problems for identifying the switch problems, five problems of demonstration of the training sequences, and eight problems in which they were able to apply the trained sequences. Participants gave verbal confirmation that they understood each strategy trained and were ready to move on to the testing problems.

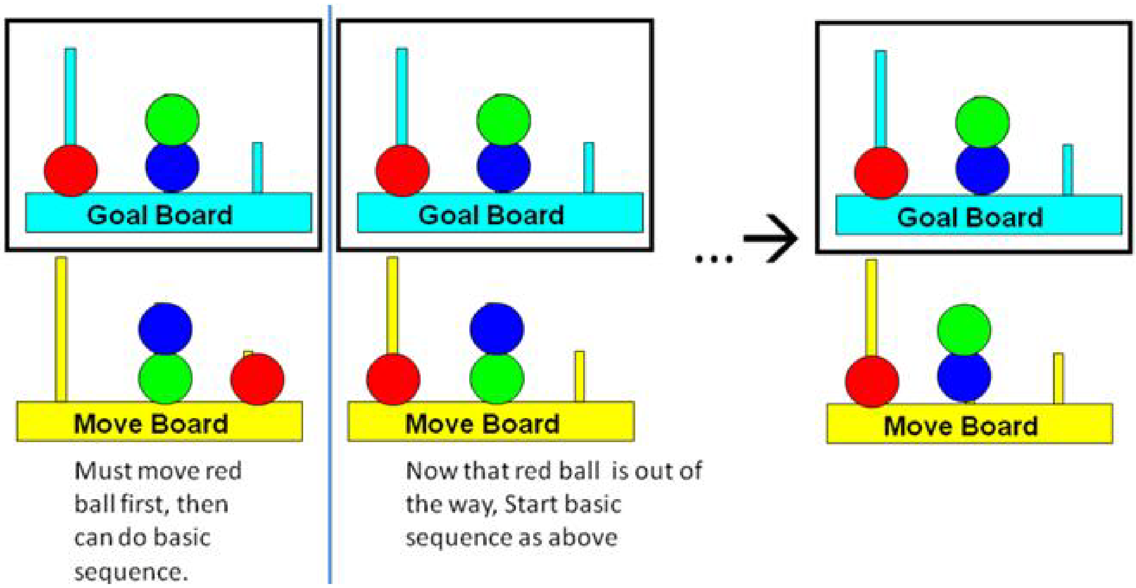

Figure 2-4. Depiction of 5-move Extended Technique 1, This technique adds one move to the beginning of the problem (5-move problem).

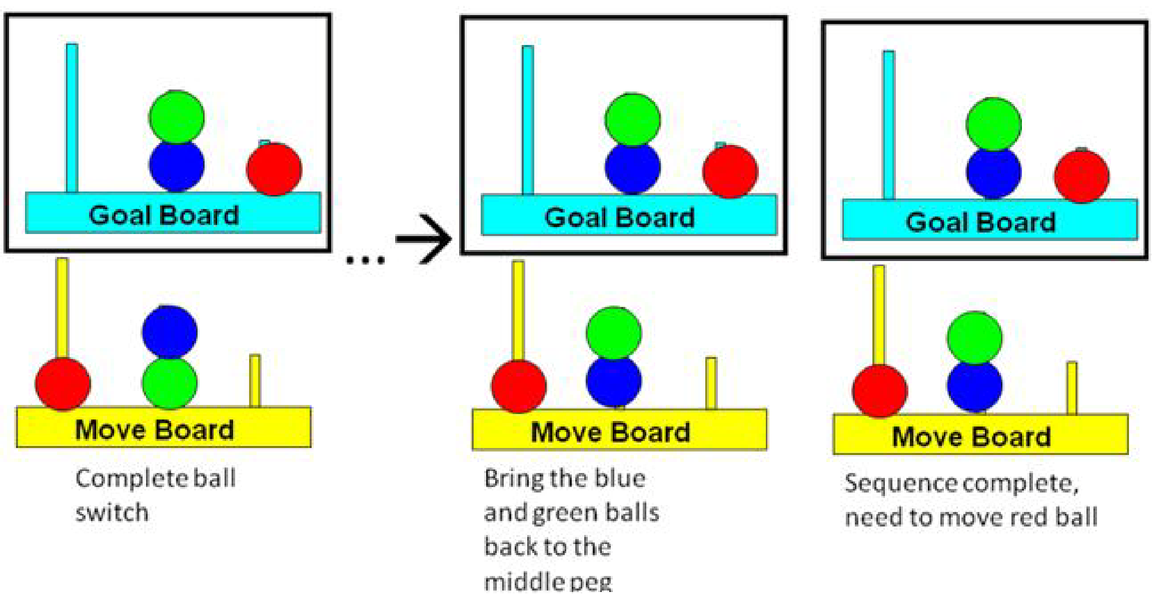

Figure 2-5. Depiction of 5-move Extended Technique 2, This technique adds one move to the beginning of the problem (5-move problem).

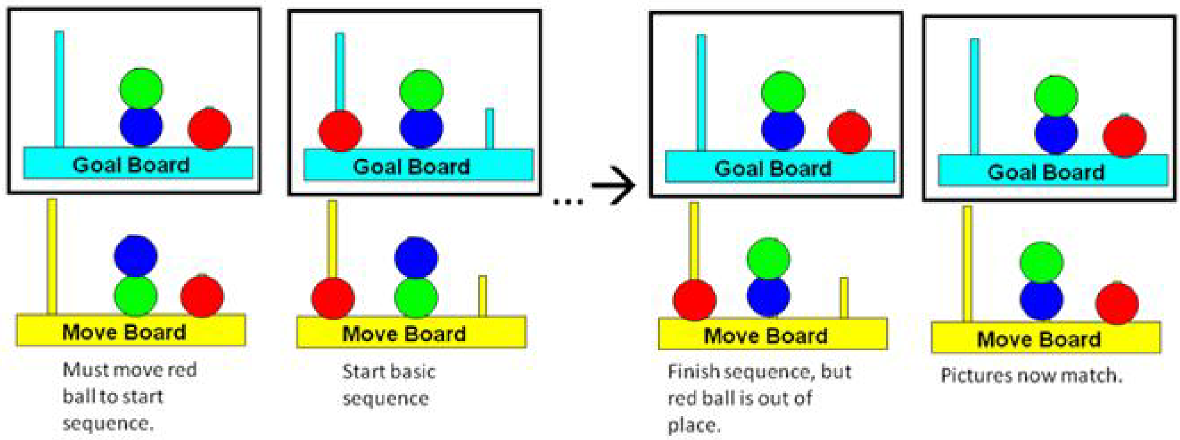

Figure 2-6. Depiction of 6-move Extended Technique, This technique adds one move to the beginning of the problem (5-move problem).

Reclassification of Problems for Analysis

There is a reclassification of the switch problems after the post-training session for the purpose of simplifying the analyses. Figure 2-7 displays a flow chart explanation of the problem reclassification. Control problems do not require reclassification since these problems are not affected by the training procedure. Switch problems are reclassified as either direct problems or indirect problems. Direct problems are those problems that match the training received (e.g., all tall switch problems presented during the post-training session would be classified as direct if participant received the tall training condition). The indirect problems are those problems that do not match the training received but are still switch problems (e.g. all middle switch problems on the post-training session would be reclassified as indirect if participants received the tall training condition). Problems will be re-classified based on training received in the second session, though pre-training problems will also be re-classified as control, indirect or direct.

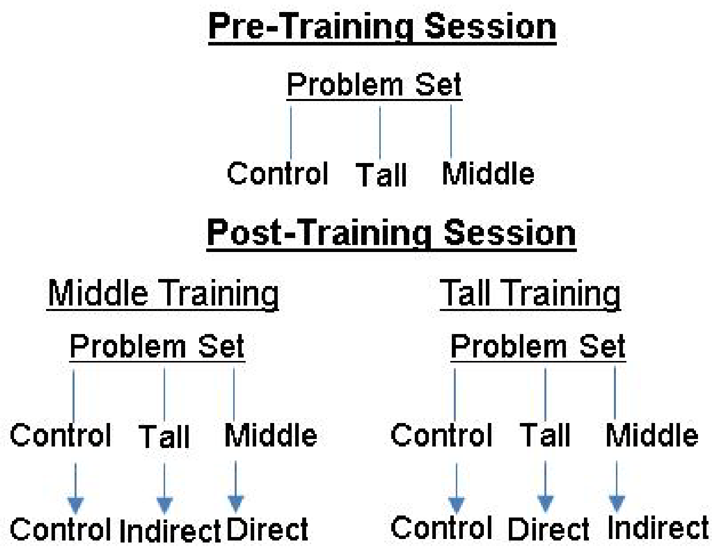

Figure 2-7. Flow Chart of Problem Type Reclassification

Procedure

Participants came to the laboratory at the University of Florida for two sessions 1-4 days apart. During the first session, participants were familiarized with the testing equipment and asked to sign the informed consent form. Participants were then given instructions on the digit symbol task. Administration of this task took an average of five minutes. Following this, participants were escorted into a sound-attenuated booth, seated in a comfortable chair, and familiarized with the EEG equipment and computer interface (electrode placement and recording discussed below).

For the pre-training session, following electrode application, participants were given instruction on the basic rules of the TOL. Practice problems for the TOL consisted of the participants solving six problems presented on a 15-inch monitor and having the research assistant give appropriate feedback and correction on their responses. Only control problems were included in these pre-training practice problems. Once the session was completed, the participant was escorted from the room and asked about their general strategy on solving the TOL problems.

For the post-training session, participants received a brief, 5-minute presentation on the rules of the TOL. Following this, each participant received either middle or tall switch strategy training. The set of problems used for post-training TOL was identical to those administered in the pre-training session. Previous research in our laboratory has suggested that identical problem presentation over a long delay (a day or more) does not increase problem solving efficiency compared to novel problems. Once completed, the participant was escorted from the room and asked about what strategy they employed while solving the TOL problems.

Electroencephalogram (EEG) Data Acquisition

Electroencephalogram (EEG) was collected from a 32-electrode NeuroScan Sintered electrode cap designed for the International 10/20 electrode arrangement and connected to a NeuroScan Synamp system. The standard 10/20 arrangement was modified by replacing two scalp leads (O1 and O2) with two drop leads (leads not connected to the cap) used for the collection of heart rate and respiration. The EEG cap was also modified from the standard 10-20 arrangement to have an additional lead, FCz, which is located between Fz and Cz. All EEG electrodes were referred to the mastoid electrode placed behind the right ear. Blinks and vertical eye movements were measured from leads placed above and below the right eye. Horizontal saccades and other horizontal eye movements were measured from leads placed just lateral to the outer canthus of each eye.

EEG signals were amplified 150,000 times and collected with an A/D sampling rate of 1000 hz. Online filter settings were placed at DC to 100 hz with a 60 Hz notch filter turned on to lessen the interference of noise from standard electrical wiring in the room.

EEG Data Processing and Quantification

Data was offline filtered with a low pass of 30hz and transferred into Matlab for eye blink correction. Eye blink correction was performed with the assistance of Independent Components Analysis on the continuous EEG files collected from each 5 minute block (Delorme and Makeig, 2004). After blink removal, three separate epochs were extracted for each problem presentation. Each epoch contained 4098 milliseconds of EEG activity with a 200 millsecond baseline. The epoch length was chosen to allow for adequate sampling of the period of interest without being too long to allow excessive eye blink or motor artifact to interfere. Trials in which EEG amplitude in any of the leads exceeded ±100mv were excluded from further analysis. The three epochs chosen allow adequate sampling across the trial to focus on two critical phases of planning and strategy application and a rest period (Figure 2-8; Rest, Problem Presentation and Problem Completion). The Rest epoch was sampled during the ITI between TOL problems while participants were sitting with eyes open viewing a red dot on the monitor. The Problem Presentation epoch was drawn from the EEG sampled following the presentation of the TOL. This epoch was taken to capture the participant's examination of the problem, and initial selection of a strategy. This epoch began 800ms post-problem presentation to ensure the frequency data collected did not include visual response to the stimuli. The Problem Completion epoch was sampled such that the epoch's end was just prior to the participant's response at the end of the trial. This epoch was taken to capture the final stages of strategy application and TOL problem solving.

EEG power (μV^2) data for all electrodes was calculated for the theta band (4-7hz), lower alpha band (8-10hz) and upper alpha band (11-13hz) via Fast Fourier Transforms using a cosine window (length: 10%). Fast fourier transforms were computed with Neuroscan, version 4.1 using the FFT batch program.

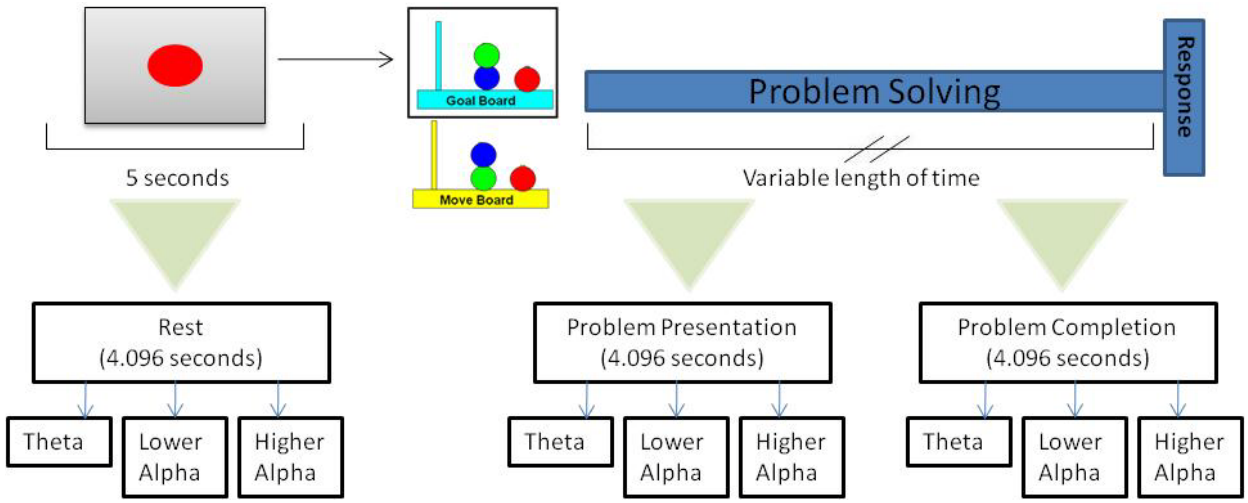

Figure 2-8. Epoch selection for Rest, Problem Presentation and Problem Completion

CHAPTER 3
RESULTS

Behavioral and EEG data were analyzed using repeated measures mixed factor ANOVAs. Post-hoc follow-up analyses were conducted using estimated marginal means and Bonferroni corrected methods to ensure that the type I error was not violated[1]. Greenhouse-Geisser tests are reported as there were significant deviations from sphericity on many of the variables, though the Sphericity Assumed degrees of freedom are presented for convenience. A table of correlations involving the behavioral variables can be found in Appendix B.

Behavioral Data

In order to evaluate performance pre- and post-training, the variables of proportion of correctly solved problems (portion correct), the time used to correctly solve problems

[1] Post-hoc follow-up tests were also completed with the Least Squares Difference procedure (essentially, no p-value correction) and similar results were obtained.

(solution time), and the proportion of trials in which the participant did not make a response (proportion no response) were examined. A mixed factor three-way ANOVA was conducted for each dependent variable with age (older, younger), session (pre-training, post-training) and problem type (direct, indirect, and control) entered.

To better understand the effect of training across age group and problem type, a measure of performance change was calculated. For each problem type, a measure of the percentage of change between the pre- and post-training scores was calculated [(Post-score – Pre-score)/Pre-score] * 100. This score allows a comparison of benefit from training across the age groups without a confound of the differential performance between age groups found in the pre-training session[2]. A larger change score indicates larger improvement on the post-training session in relation to the pre-training session. For each performance score, results and analysis with the performance change score are presented following the results and analysis with the raw session-by-session means. Group means and standard deviations can be found in Table 3-1 for all behavioral measures.

Proportion Correct

Means of the raw performance scores showed, as expected, better performance for the younger adults as compared to the older adults and this was confirmed in the analysis by a main effect of Age (F (1, 54) = 28.379, p < .001). Additionally, a main effect of Session (F (1, 54) = 24.931, p < .001) was found and the means demonstrated that participants had better performance in the post-training session as compared to the

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[2] A measure of performance gain in which the formula was (Post-score – Pre-score) was calculated. Similar results were obtained as the presented variable.

pre-training session (Figure 3-1). A main effect of Problem type (*F* (2, 108) = 5.554, *p* = .006) was further examined in follow-up analyses with means demonstrating that control problems had a lower score on proportion correct as compared to the indirect (*p* = .032) and direct problems (*p* = .026). Indirect and direct problems do not differ from each other.

Table 3-1. Means and Standard Deviations for Behavioral Measures

	Pre-Training		Post-Training		Percent Change	
	Older	Younger	Older	Younger	Older	Younger
Proportion Correct						
Control	00.56 (0.16)	00.80 (0.17)	00.61 (0.18)	00.85 (0.20)	18.0%(.48)	07.0%(.17)
Indirect	00.59 (0.17)	00.82 (0.20)	00.69 (0.14)	00.89 (0.20)	24.2%(.37)	09.8%(.18)
Direct	00.57 (0.20)	00.85 (0.19)	00.71 (0.20)	00.87 (0.20)	44.2%(.78)	3.0%(.18)
Solution Time (sec)						
Control	24.75 (4.52)	17.60 (3.61)	24.62 (5.09)	13.20 (3.52)	-0 .1%(.19)	24.3%(.12)
Indirect	24.42 (5.35)	14.20 (3.89)	19.87 (5.23)	08.35 (2.08)	17.3%(.24)	39.1%(.16)
Direct	24.30 (5.42)	14.50 (3.25)	18.39 (5.14)	07.83 (1.57)	21.1%(.16)	47.5%(.13)
Proportion No Response						
Control	00.14 (0.10)	00.03 (0.05)	00.11 (0.13)	00.01 (0.02)	--	--
Indirect	00.12 (0.12)	00.01 (0.03)	00.04 (0.06)	00.00 (0.00)	--	--
Direct	00.14 (0.14)	00.01 (0.03)	00.03 (0.07)	00.00 (0.00)	--	--

Note: Scores are presented with standard deviations in parentheses. For the percent difference score, a higher number indicates more improvement. Solution time scores were revered in sign so that higher scores indicate better performance in the post-training session

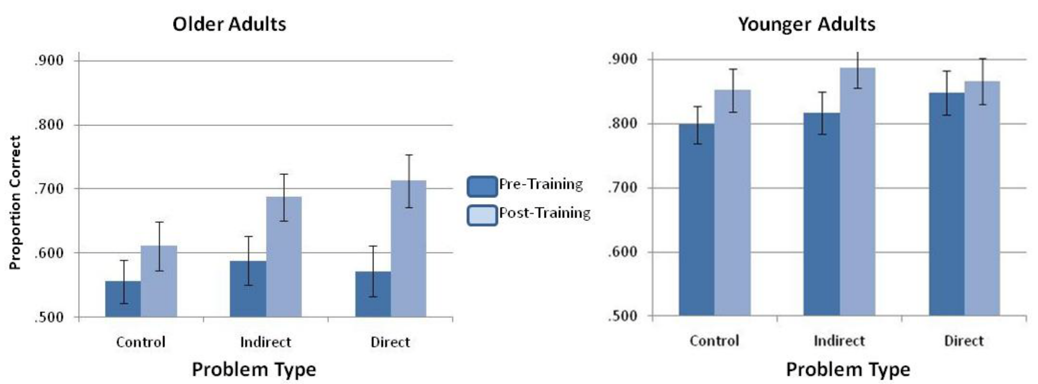

Figure 3-1. Mean proportion correct measure for older and younger adults

The change score of proportion correct yielded a main effect of Age (*F*(1, 54) = 8.929, *p* = .004) with the means of the older adults showing larger benefits as compared to younger adults on all problem types (Figure 3-2). Although, this measure should be interpreted with caution, as pre-training means on the measure of proportion correct for the younger adults suggests a ceiling effect with little room for improvement on the post-training session[3] (Figure 3-1). In light of this possible ceiling effect, older adults were tested separately and although the means suggest differential improvement across problem type this is not supported statistically.

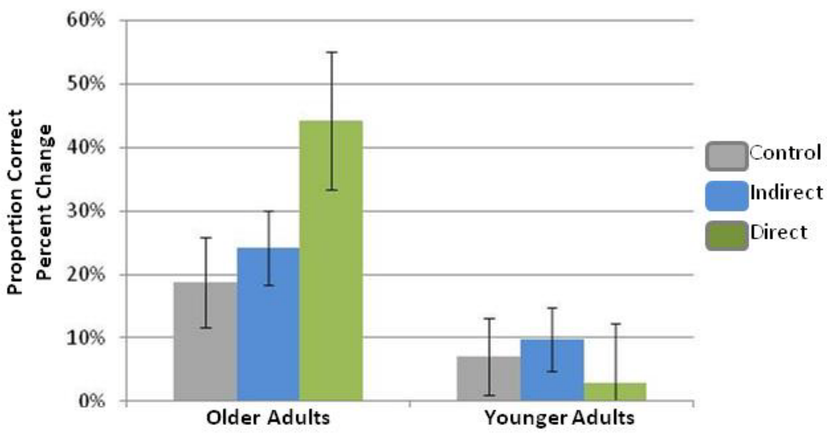

Figure 3-2. Change score measure for proportion correct for older and younger adults

Solution Time

Raw solution time results indicated younger adults were, as expected, faster at solving the TOL problems as compared to the older adults, confirmed by a main effect of Age ($F(1, 54) = 143.829$, $p > .001$). This was qualified by a three-way interaction of Session x Problem type x Age ($F(2, 108) = 3.579$, $p = .038$). Follow-up analyses indicated that though the younger adult group significantly improved following training on all three problem types in the post-training session (p's < .001), the older adult group only improved on the indirect and direct problems in the post-training session (p's <

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[3] The ceiling effect was not statistically supported with proportion correct values being significantly different from 1 for both age groups at all problem types (p's < .003).

.001). This demonstrates the importance of the training for the older adult group as they showed improvement in only the trained problems and not the control problems (*p* = .983).

As suggested in Figure 3-3, younger adults were faster at solving the indirect and direct problems in the pre-training session as compared to the control problems and this was statistically supported in follow-up analyses with younger adults only when comparing solution time means for each problem type. While the direct and indirect problems did not differ from each other (*p* = .999) both means showed better performance than the control problems (*p*'s < .001) on the pre-training session. It is possible that younger adults had discovered the strategy needed to solve switch problems and were, therefore, able to apply the strategy to the indirect and direct problems before formal training occurred.

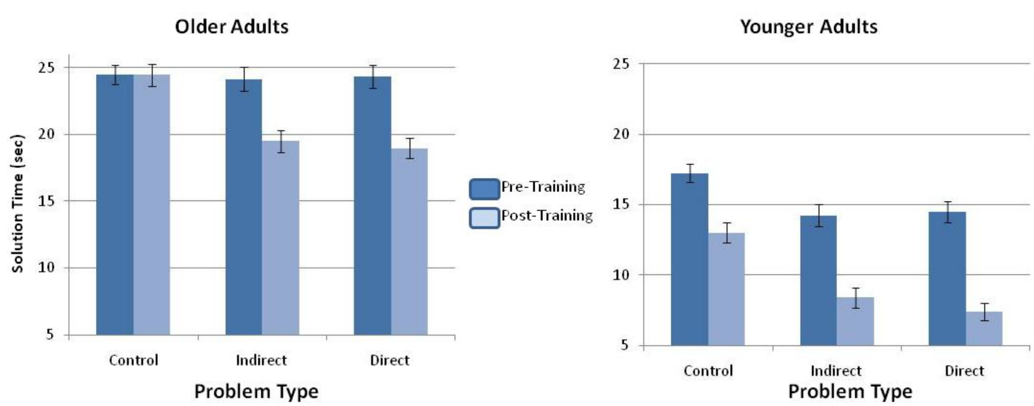

Figure 3-3. Mean solution time measures for older and younger adults

The change score for solution time yielded a main effect of Age (F (1, 54) = 50.583, $p < .001$) with younger adults demonstrating more improvement as compared to the older adults (Figure 3-4). A main effect of Problem type (F (2, 108) = 41.867, $p < .001$) was further investigated in post-hoc analyses showing that all three problem types were significantly different from each other, with direct problems showing the most improvement (p's < .011). Thus, both age groups showed a clear improvement on the direct problems and were able to successfully transfer the strategy to the indirect problems in the post-training session.

While the interaction of Problem type x Age was not significant, the graph of their means suggests an interesting difference between age groups. The younger adult group improves in their performance on all three problem types, with up to 50% faster solution times for the direct problems. Older adults, on the other hand, only improve on the indirect and direct problems. Both these findings are consistent with raw score results. This again highlights the importance of the older adults receiving the strategy training. While the younger adults are benefitting more from the strategy training than control training improvements occur for all problems types, the lack of improvement on the non-trained problems indicates that older adults only improved from the training and not from general practice effects. The fact that older adults only improved on the trained problems demonstrates the importance of the training since improvement from general practice effects was not witnessed for the older adults group. It was, however, shown for the younger adult group.

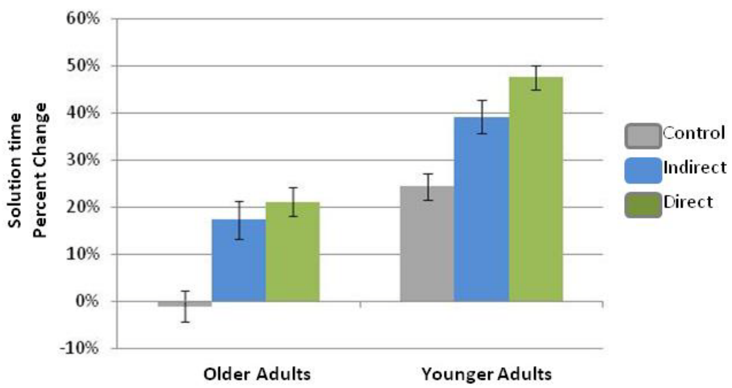

Figure 3-4. Change scores for solution time for older and younger adults

Proportion of No Response

The proportion of no responses across age groups and problem types was quite low[4] (Table 3-1) but results were able to further illuminate the importance of training for the older adult group. A three-way interaction of Session x Problem type x Age (F(2, 108) = 4.608, p = .020) was further examined in post-hoc analyses. The older adults demonstrated a significant decrease in the number of no responses in the post-training session for only the indirect and direct problems (p's < .001) with no drop in the number of no responses for the control problems (Figure 3-5; p = .153). This pattern is showing a transfer of benefit to the indirect problems in the post-training session. Younger adults did not demonstrate significant differences between problem type or session in this measure, though the pre-training scores suggest little room for improvement on this measure.

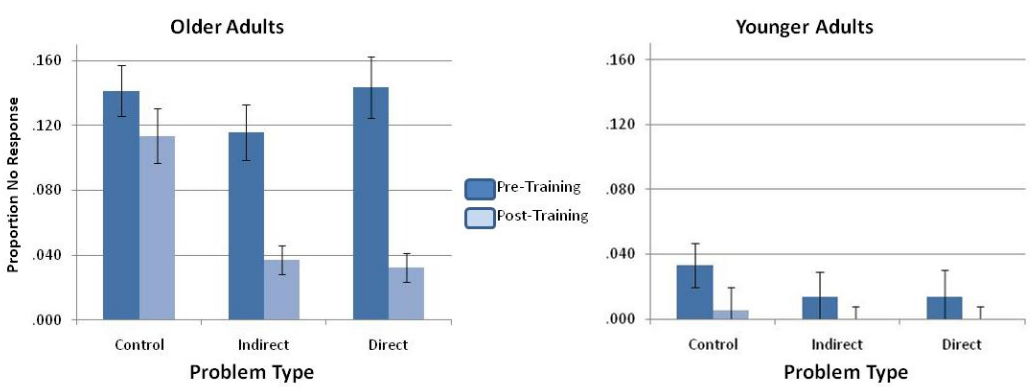

Figure 3-5. Mean proportion of no responses for older and younger adults

Electroencephalogram (EEG) Data Analysis

The frequency bands of theta, lower alpha, and upper alpha were investigated across age, session, lead, and epoch time to understand the effects of training and age

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.[4] A one-way t-test against 0 demonstrated a lack of floor effect for either age group on any problem type (p's < .009) on brain activity. A repeated measures ANOVA was conducted for each frequency band with age (older, younger) session (pre-training, post-training) and problem type (direct, indirect, and control). For the theta frequency band the midline lead set of Fz (frontal) and Pz (parietal) and the frontal lateral lead set of FC3 (left frontal) and FC4 (right frontal) were separately assessed. The lateral set is used to examine laterality effects in the theta band. Based on research reviewed in the introduction, the lower alpha frequency band was assessed with the midline lead set of Fz (frontal) and Pz (parietal). For the upper alpha band, the lead of Pz (parietal) was tested. Lead sets analyzed at each frequency band were chosen by adopting methodology previously used in comparison literature (Cummins et al., 2007; McEvoy et al., 2001; Gevins et al., 1997). The lower alpha band is investigated at the frontal and parietal sites to understand its functional significance to the task and the topographic changes expected during TOL problem solving (Sauseng, Klimesch, Schabus, et al., 2005).

ANOVA tests were completed separately for each epoch time (rest, problem presentation, problem completion) and are presented below for each frequency band and lead set. The organization of this section is as follows: The theta band will be presented at the frontal and parietal midline sites for each epoch time, followed by the frontal lateral set for each epoch time. The alpha band will follow with comparisons between the frontal and parietal regions for each epoch time for the lower alpha band and investigations of the parietal region for the upper alpha frequency band. For convenience, an outline of the main findings from each of these ANOVAs is presented in Appendix C. At the beginning of each frequency band section, topographic maps for that frequency are presented to provide a general overview of activity in that band.

The Theta Frequency Band

Topographic maps of the theta frequency band for both younger and older adults are presented in Figure 3-6. For the older adult participants, there does not seem to be a large difference in theta power between the three epoch types. There does, however, seem to be an increase in theta power in the post-training as compared to the pre-training session, especially for older adults. For the younger adults, there is also an increase in theta power from the rest to the problem presentation and problem completion epoch. Note the difference in scales between groups employed to highlight the differences for each group separately. The older adults show significantly less theta power as compared to the younger adults.

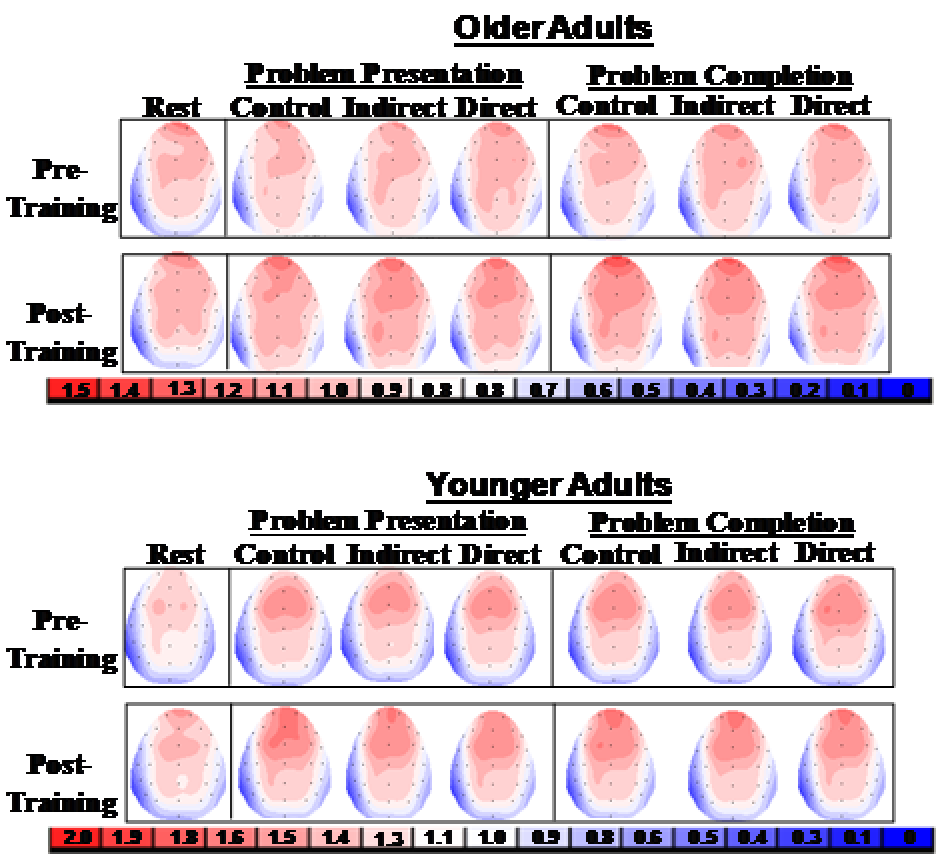

Figure 3-6. Topographic plots of Theta for Older and Younger Adults. Note the different axis values used to maximize the visual depiction of the topographical changes across the head for each age group individually.

Frontal and Parietal Activity in the Theta Frequency Band

In the separately conducted ANOVAs for each epoch time there was a main effect of Lead (*F's* (1, 54) > 12.629, *p's* < .001) and of Age (*F's* (1, 54) > 36.227, *p's* < .001). Follow up analyses conducted show that in all epochs the frontal lead has more theta power as compared to the parietal lead (*p*'s < .001) and younger adults had more theta power as compared to the older adults (Figure 3-7). Since this main effect of age was found in all three epoch times, the younger adults show more theta power as compared to the older adults.

Additionally, all three epochs had a Session x Lead interaction (*F's* (1, 54) > 5.517, *p's* < .023). This interaction was followed up with analyses conducted separately for each lead type, and these showed that only the frontal regions significantly increased in theta power between the pre-and post-training session (*p's* < .014). The parietal region did not show a change in theta power between the pre- and post-training session. As demonstrated in Figure 3-7, this is found in both age groups. The fact that this was found in both age groups shows a lack of developmental change across the lifespan.

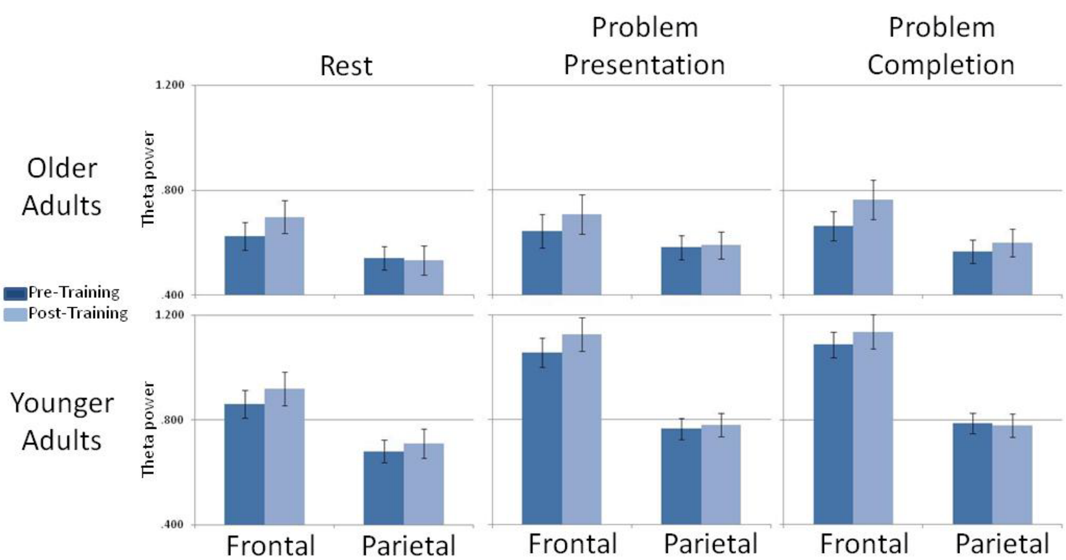

Figure 3-7. Theta power in the frontal and parietal leads during all three epoch times

During the problem presentation and problem completion epochs, there was also a Age x Lead interaction ($F(1, 54) = 21.52$, $p < .001$). This interaction was followed up separately for each age group which showed that the younger adults had a greater difference in theta power between the frontal and parietal regions (*p's* < .001) as compared to the older adults (*p's* < .018; Figure 3-7). Younger adults are demonstrating larger differentiation between frontal and parietal regions, with greater theta power at the frontal leads during both epochs taken during the TOL presentation and problem solving. As expected, older adults are greatly lacking in frontal midline theta as compared to the younger adults. While younger adults have larger theta power at both the frontal and parietal leads, the frontal difference between age groups is larger than the parietal difference in both the pre- and post-training sessions.

During only the Problem Completion epoch, a three-way interaction of Session x Problem type x Lead ($F(2, 108) = 5.94$, $p = .004$) demonstrated training differences between problem types in the theta band (Figure 3-8). Post-hoc analyses conducted separately for each problem type indicate that both the control and indirect problems increase in theta power between the pre- and post-training conditions but only in the frontal regions (p's < .038) with direct problems approaching significance (p=.10). There were no changes in theta power in the parietal regions across problem types or session. Figure 3-8 demonstrates that this increase is apparent in both the older and younger adults, though the means clearly indicate a larger effect in the older adults. Inspection of raw mean increases in the post-training session shows that older adults have a larger increase in each problem type as compared to younger adults, though follow-ups with each age group separately did not supported this claim.

In review, the theta band at the frontal and parietal leads showed clear age differences with the older adults having significantly less theta power as compared to the younger adults, specifically in the frontal regions. A differential increase in the frontal regions in the post-training session was found for both younger and older adults. The effect of problem type, while small, showed larger increases in theta power in the indirect and control problems as compared to the direct problems during the problem completion epoch.

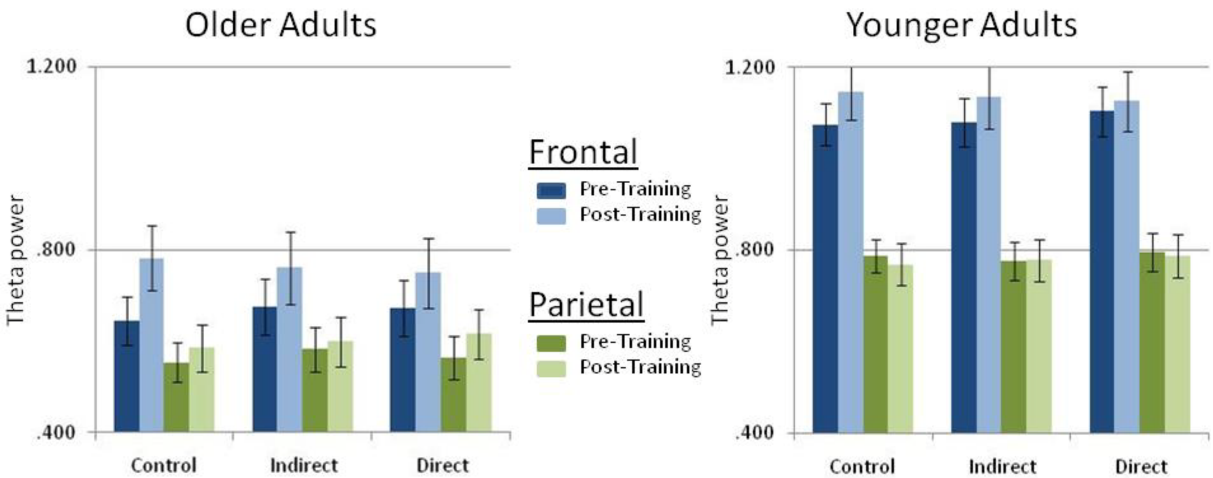

Figure 3-8. Theta power at the frontal and parietal sites during the problem completion epoch

Lateralized Frontal Activity in the Theta Frequency Band

In the separately conducted ANOVAs for each epoch time, there was a main effect of lead, left versus right (F's (1, 54) > 55.03, p 's < .001) at all epochs. Follow-up analyses showed that the right frontal region shows larger theta power as compared to the left frontal region (p < .001) at all three epochs. Similar to the midline theta analysis all three epochs showed a main effect of Age with the younger adult group showing larger theta power as compared to the older adult group in both lateral frontal leads (F's (1, 54) > 16.40, p 's < .001). A main effect of Session was only found in the problem presentation and problem completion epochs, with larger theta power in the post-training as compared to the pre-training session (*F*'s (1, 54) > 4.96, *p* 's < .030).

During only the Problem Presentation epoch, a three-way interaction of Session, x Lead, and x Age ($F(1, 54) = 4.34$, $p = .042$) was followed up separately for each age group. The older adult group showed an increase in theta power in the left frontal lead in the post-training session as compared to the pre-training session ($p = .016$), with no increase found in the right frontal lead ($p = .401$). The younger adults do not show any significant increase across session in theta power in either the right or left frontal leads (Figure 3-9). Thus, during the initial TOL planning, older adults were showing an increase in activity in the post-training session as compared to the pre-training session for the left frontal lead while the younger adults were not displaying a similar increase. Older adults show less overall activity in the left frontal hemisphere as compared to the right and there is an increase in this region in the post-training session. Thus, as with the frontal region analysis, older adults are showing more increases in the post-training session as compared to the younger adults. This is an interesting finding as it would be expected that the younger adults show larger increases since their performance was better as compared to the older adults.

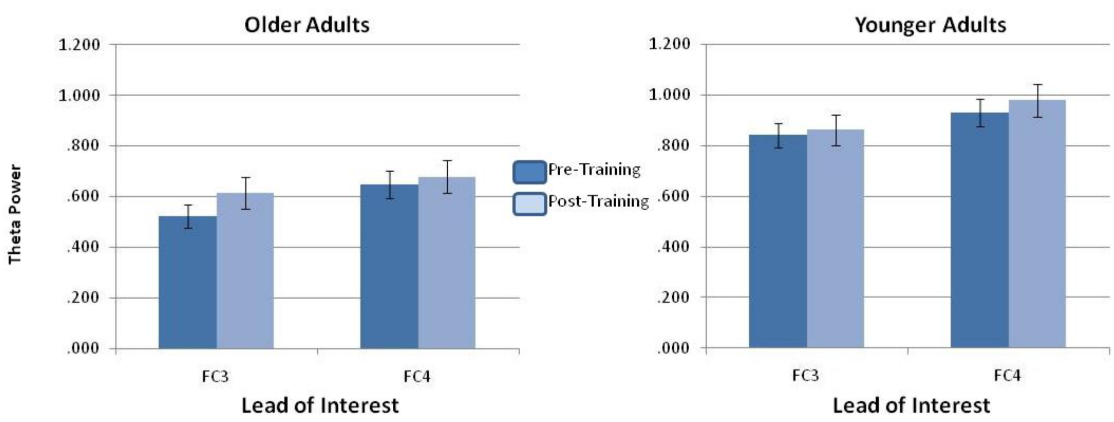

Figure 3-9. Lateral frontal theta power in the problem presentation epoch

During the Problem Completion epoch, a two-way interaction of Session x Problem type ($F(2, 108) = 3.45$, $p = .037$) was further investigated by an analyses of each problem type. As shown in Figure 3-10, only the control problems showed an increase in theta power in the lateral electrodes in the post-training session ($p = .032$). Though the indirect and direct problems are not significantly increasing in the post-training condition, the means suggest a similar pattern as found in the control problems. This pattern is similar to the increases seen in the midline lead analysis. Given that the importance of age is to be highlighted here, an exploratory follow-up was conducted which showed that the increase in theta power in the control problems was found only for the older adult group ($p = .025$). The younger adult group did not show differences between the pre- and post-training condition in any problem type.

The lateral frontal theta analysis showed similar changes across age, with the younger adults showing larger theta values as compared to the older adults at all three epoch times. Also similar to the midline lead analysis, the older adults showed larger increases in the post-training session as compared to the younger adults (Figure 3-7 and Figure 3-9). The control problems showed the largest increases in theta power, though as was found in the midline lead analysis, the figure suggests increases in all three problem types is evident (Figure 3-8 and Figure 3-10).

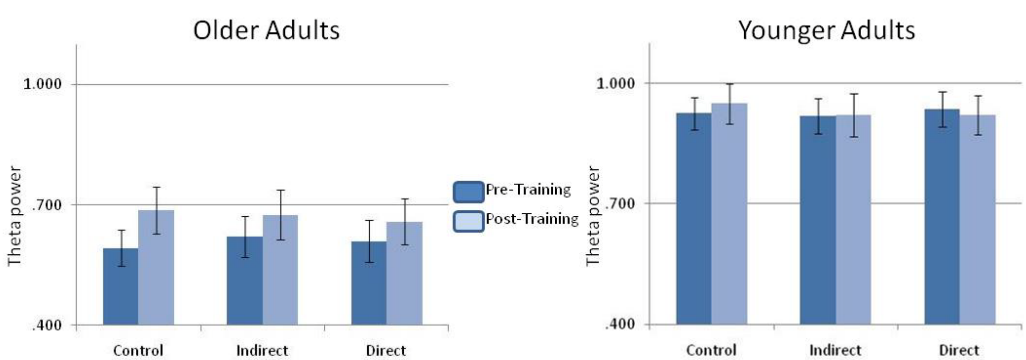

Figure 3-10. Lateral frontal theta power in the problem completion epoch

Frontal and Parietal Activity in the Lower Alpha Frequency Band

Topographic maps of the lower alpha frequency band for both younger and older adults are presented in Figure 3-11. A clear decrease in power between the rest and TOL epoch times are present in both younger and older adults, though possibly stronger for younger adults.

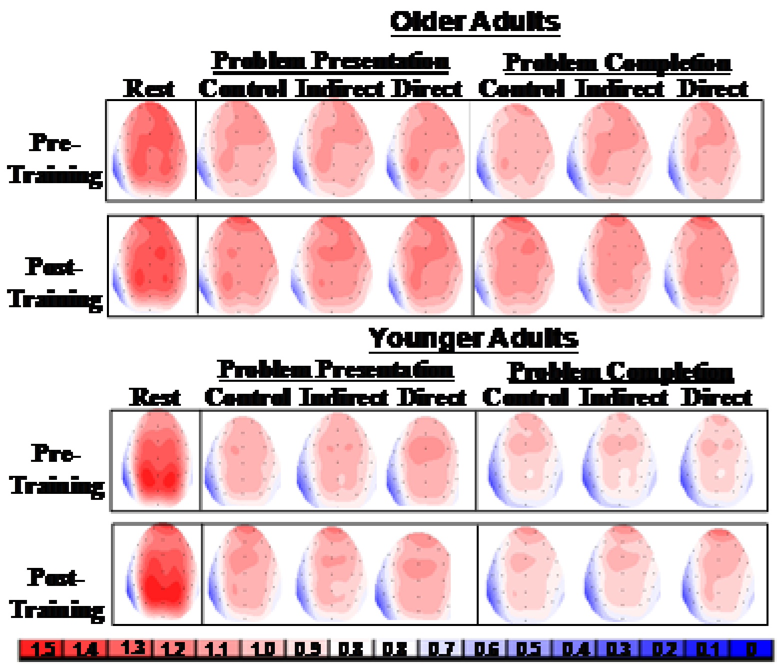

Figure 3-11. Topographic plots of Lower Alpha for Older and Younger Adults.

In the separately conducted ANOVAs for each epoch time, there was no significant main effect of Age. While the theta frequency band showed large age differences, this alpha band did not follow a similar pattern. A main effect of Session was found in rest and in the problem completion epoch, with an increase in lower alpha in the post-training session as compared to the pre-training session (F's (1, 54) > 4.470, p 's < .039).

Across the three epochs, there is a change in topography of lower alpha. In the rest epoch, there was a Lead x Age interaction (F (1, 54) = 4.552, p = .037). Analyses separately conducted for each age group reveal that younger but not older adults have larger alpha power in the parietal region as compared to the frontal regions (p = .044). Older adults had a non-significant difference in the opposite direction, as shown in the left panel of Figure 3-12. During the problem presentation and problem completion epochs, the frontal regions have larger lower alpha power as compared to the parietal regions (p's < .003). Both the lack of a Lead x Age interaction and Figure 3-12 show that this is true for the younger and older adults.

Unlike the theta frequency band, there was not a significant different in age, though Figure 3-12 suggests a pattern in the direction of younger adults showing more lower alpha as compared to the older adults. The change in topography noted across epoch times is strongest for the younger adults as the older adults show a similar pattern of lower alpha across all three epoch times.

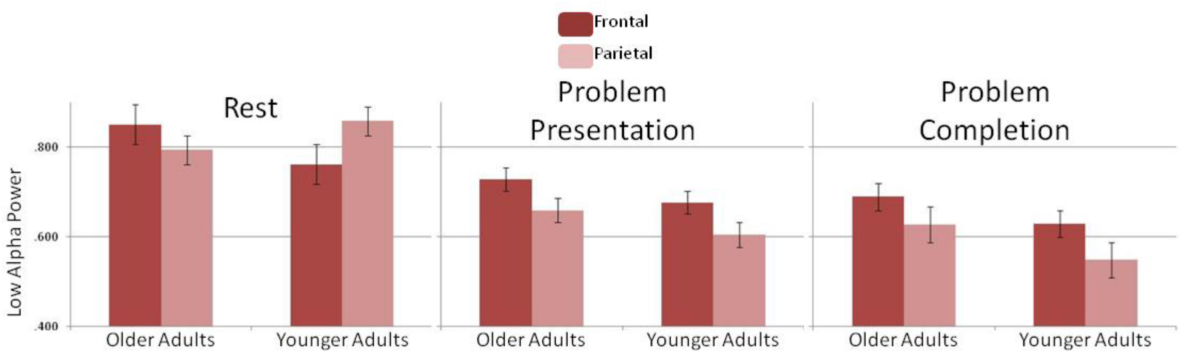

Figure 3-12. Lower alpha power in the frontal and parietal regions during all three epoch times

Parietal Activity in the Upper Alpha Frequency Band

Topographic maps of the upper alpha frequency band for both younger and older adults are presented in Figure 3-13. A clear decrease in power between the rest and TOL epoch times are present in both younger and older adults, and this appeared stronger for older than younger adults.

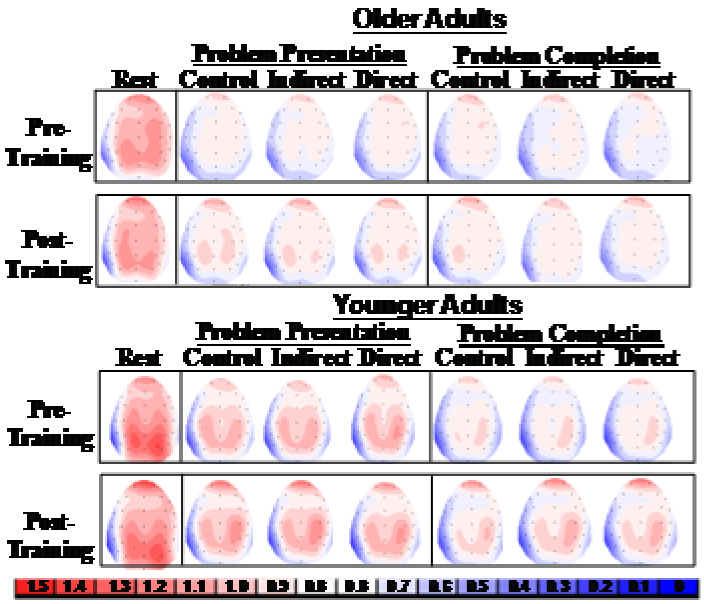

Figure 3-13. Topographic plots of Upper Alpha for Older and Younger Adults.

Analyses conducted with the upper alpha frequency band did not have any significant interactions or main effects. This demonstrates an important contrast to the other frequency bands. While both the lower alpha and theta band were modified by the independent variables, the upper alpha band was not. Thus, the changes seen in the lower alpha and theta frequency bands are not due to general changes in all frequency bands. It is also not surprising that the upper alpha frequency band did not produce changes across age or task as this band is thought to be associated with visual stimulation (Gevins et al., 1997), something that was consistent across both sessions and all problem types in the present study.

Individual Factors Contributing to Successful Strategy Application

The effect of processing speed on cognitive variables (Salthouse, 2005; Riccio, Wolfe, Romine, Davis and Sullivan, 2003) and its predictive ability on successful strategy application across the lifespan has been previously explored (Verhaeghen et al., 1996). Individual patterns of cognitive style have been related to performance differences as well as differences in EEG patterns (Gevins et al., 1997). Employing similar methods to Gevins and Smith (2000), participants were split into high processing speed (HPS) and low processing speed (LPS) groups based on their performance on the digit symbol task. Within each age group, a median split determined the placement of participants into either the HPS or LPS group. Table 3-2 presents pertinent information for these subgroups of participants. This exploratory analysis was conducted to further understand the importance of processing speed in TOL performance, strategy application and EEG patterns across the lifespan.

Table 3-2. Demographic Data for Low and High Processing Groups

	Age		*N*		Digit Symbol Score	
	Older	Younger	Older	Younger	Older	Younger
Low Processing Speed	71.87(5.31)	20.30(1.65)	12	16	41.58(6.65)	64.13(5.03)
High Processing Speed	68.64(3.65)	20.11(1.48)	12	16	59.42(6.87)	76.75(3.64)

Two preliminary ANOVAs were conducted to verify the median split procedure. The first univariate ANOVA was run separately for each age group and confirmed significantly different digit symbol mean scores between the high and low processing speed groups for each age group (Figure 3-14; *F's* $(1, 52) > 178.88$, *p's* $< .001$). The second univariate ANOVA was also run separately for each age group and confirmed the lack of age difference between the HPS and LPS groups (*p*'s $> .097$). Thus, differences found between these groups cannot be attributed to group differences in age. This is important to demonstrate that if there are differences between these groups it is not due to cognitive development which occurs within each of the age groups. For the younger adults this would be cognitive improvements and for the older adults this would be cognitive decline.

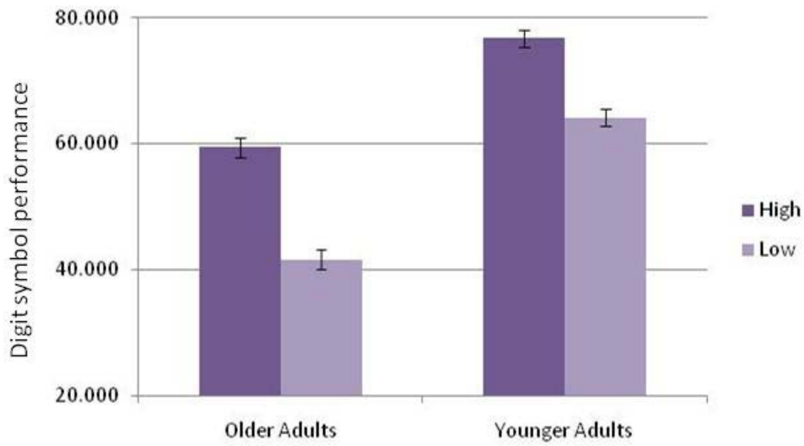

Figure 3-14. Digit symbol means for LPS and HPS groups for younger and older adults

Primary analyses were conducted to evaluate differences in HPS and LPS across behavior and EEG variables. A repeated measures mixed factor ANOVA was performed with the variables of processing speed (high, low), age (older, younger), session (pre-training, post-training) and problem type (direct, indirect, and control). To confine these exploratory analyses, dependent variable choices were based on findings from the ANOVA analyses completed in the previous section. The behavioral measures explored are solution time both within each session and the change score. Proportion correct was not included due to a ceiling effect for younger adults in the pre-training session. The measure of proportion of no responses was omitted due to floor effects in the pre- and post-training session for the younger adult group. EEG measures include the theta frequency band at midline frontal/parietal sites and lateral frontal sites at each epoch time. Lower alpha frequency band was explored but did not produce significant findings related to processing speed. The high alpha band was not included in these analyses due to insignificant results as reported above. In the following section, only significant findings involving the difference between processing speed groups will be highlighted. All of the significant effects found above were replicated in these analyses.

Behavioral Analyses Between the High and Low Processing Speed Groups

The measure of solution time across session did not show any significant effects involving the processing speed group variable. The measure of the change score for solution time showed a three-way interaction of Age x Problem Type x Processing speed group, F (2,108) = 3.371, p = .046, which was further investigated in follow-up analyses conducted separately for each age group. As shown in Figure 3-15, the younger adults do not differ in performance changes between the LPS and HPS groups on any of the problem types. For the older adult group, the LPS group has more improvement on the indirect problems as compared to the HPS group (p = .007). There were no significant differences between these older adult groups on the other problem types. While this is a surprising finding, it may be interpreted as the LPS group benefiting from the strategy training more because this allows them to maximize their resources and gain better cognitive control. This is especially important for older adults and those with low processing speed ability. Further elaboration on this point will be highlighted in the discussion. It is an interesting difference which may only be attributed to a small number of subjects involved in each group.

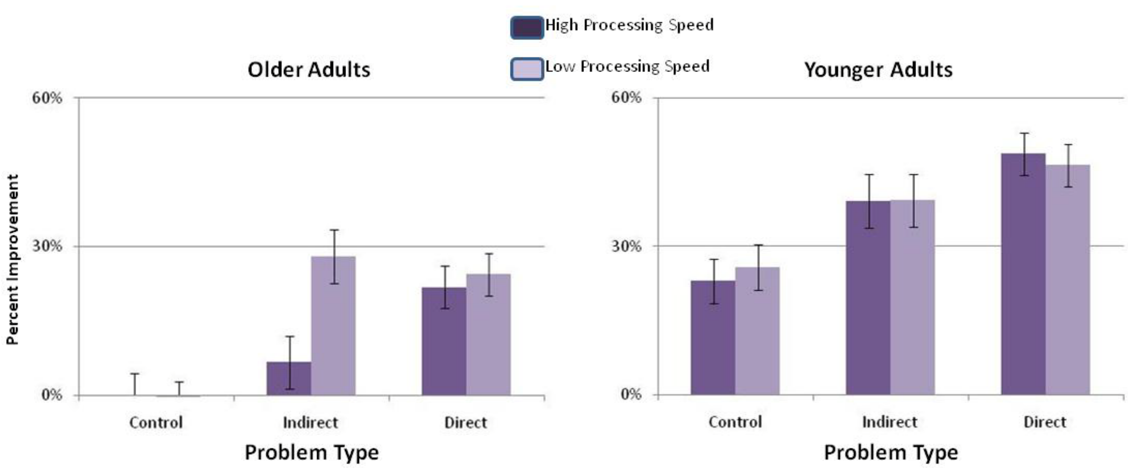

Figure 3-15. The change score differences in solution time between LPS and HPS groups

Frontal and Parietal Activity in the Theta Frequency Band Between High and Low Processing Groups

In the separately conducted ANOVAs for each epoch time there was an interaction of Lead x Age x Processing speed group (*F's* (1, 52) > 5.934, *p's* < .018). Post-hoc follow-up analyses conducted for each epoch time were done separately for each age group, and mean results are shown in Figure 3-16. As was found with the behavioral data, the younger adult group shows no significant differences between the LPS and HPS groups for any of the epochs. Interestingly, in older adults only the HPS group shows a significant difference between the frontal and parietal leads (*p* < .001); there is no significant difference between these leads for the LPS older adults. Thus, both younger adult groups as well as the HPS older adults group showed differential activity between the frontal and parietal regions during all three epoch times.

During the problem presentation and problem completion epochs, the HPS older adults show larger frontal theta power as compared to the LPS older adults (*p's* < .05). During the rest epoch there was a difference in the same direction, but it was not significant. It is possible then that this difference is inherent and found to be more reliable or exaggerated during difficult cognitive stimulation.

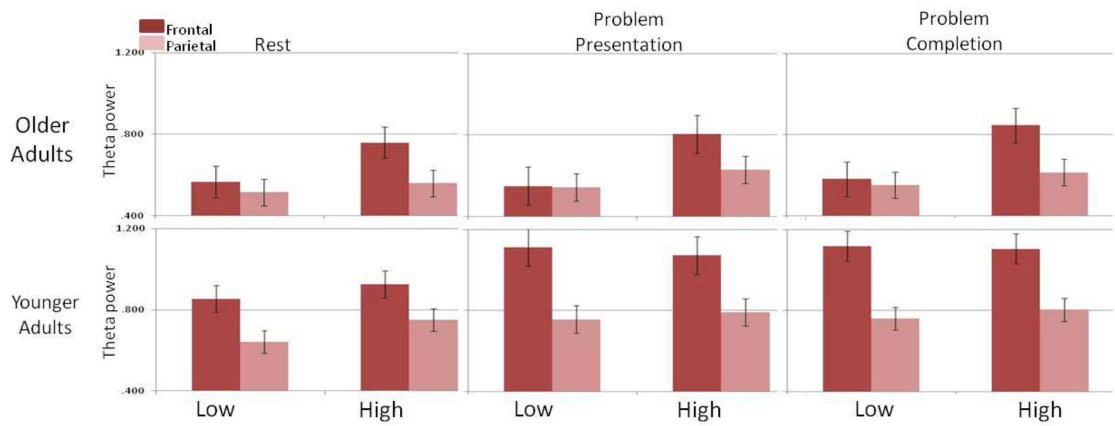

Figure 3-16. Frontal and parietal theta power between LPS and HPS groups at all three epochs

Lateral Frontal Activity in the Theta Frequency Band Between High and Low Processing Groups

In the separately conducted ANOVAs, there was an interaction of Lead x Processing speed group in each epoch time (F's (1, 52) > 7.210, p's < .010). Post-hoc analyses conducted separately for each processing speed group showed that in all three epoch times, the HPS group showed larger theta power in the right as compared to the left lead (p's < .001). The LPS group demonstrated a similar pattern with less differentiation between hemispheres. While Age was not a part of the interaction, exploratory post-hoc analyses conducted separately for each age group confirmed that this pattern between HPS and LPS groups is reflected in both age groups (Figure 3-17).

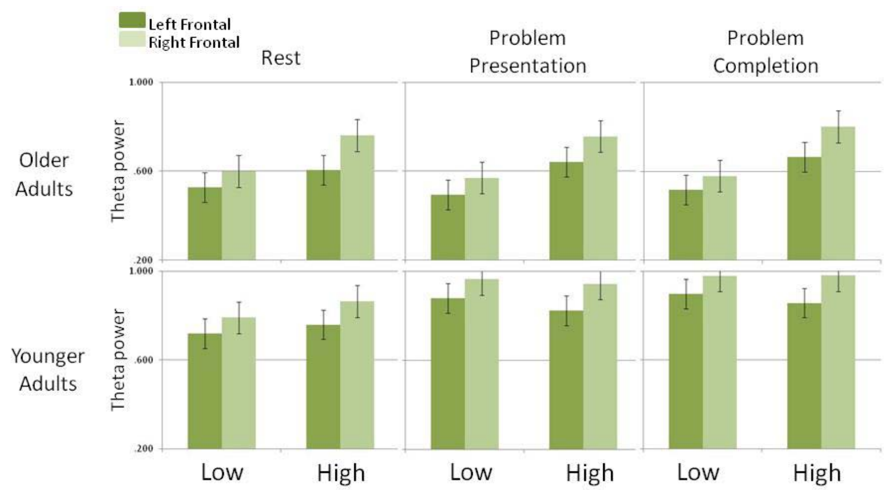

Figure 3-17. Lateral frontal theta activity between LPS and HPS groups at all three epochs

CHAPTER 4
DISCUSSION

The strategy training designed to reduce working memory load in younger and older adults engaged in a difficult planning task was successful in improving performance on both directly and indirectly related problems. Behavioral measures indicate that the strategy training produced larger gains in the younger as compared to older adults. As expected, the older adults showed decreased FM-theta as compared to the younger adults, a difference that was somewhat different in the post-training session, as the older adults showed larger increases in FM-theta in the post-training condition as compared to younger adults. The alpha frequency band as measured from the parietal cortex was not affected by task, training, or development. The lower alpha band showed topographic shifts from the parietal to frontal cortices during epoch times in younger, but not older, adults. Individual differences in processing speed in older adults only was found to affect both performance and EEG signatures during task and rest conditions, suggesting this affects both state and trait functions of the EEG signatures.

The discussion that follows will focus on several key issues which were raised by this research to gain further understanding of changes across development in strategy application and neuronal activity. A discussion of the changes across the lifespan in strategy benefits, EEG signature changes and the impact of processing speed will be highlighted.

Differences in the Benefits of Strategy Training Across the Lifespan

The beneficial impact of memory training, even into very old age, has been clearly demonstrated in a multitude of paradigms (Becic et al., 2008; Bottiroli et al., 2007;

Carretii et al., 2007; Singer et al., 2003; Cavallini et al., 2003; Rapp et al., 2002; McNamara et al., 2001). As expected, in the current study both age groups were able to apply the trained strategy and demonstrated substantial improvement in both behavioral measures. Many previously conducted memory training paradigms have employed tasks which have not taxed the individual cognitively. The current study employed a task which required participants not only to spatially rearrange the balls on a peg, but to consistently update their memory for the most current locations of those balls without actually seeing the change made. During the pre-training condition, older adults exhibited significantly poorer performance as compared to the younger adults while the increase in older adults was substantial, they did not reach the levels of the younger adults in the post-training condition. In fact, the older adult participants, even after training, were not able to reach the performance levels of younger adults prior to training. This lack of improvement to the level of a younger adult does not, however, reduce the importance of the substantial improvements made by the older adults in the post-training session. Additionally, this training paradigm was quite brief and the older adults demonstrated large improvements.

The evidence of transferring the knowledge gained by training in one task to the benefit of another task has been difficult to demonstrate in previous research (Karbach & Kray, 2009). Based on behavioral results of the current study, both younger and older adults were able to transfer the trained strategy on one type of problem to another; to transfer this strategy from the directly trained problem to the indirectly related one. There are several reasons why transfer may have been evident here and lacking in other studies. First of all, the indirectly related task had many similar qualities to the directly trained task; it was not transferred to a new task, but to a related problem in the same task. The process to solve and the goal of the indirectly related task were very similar to the directly trained task. Nonetheless, the adaptation of the trained strategy to the indirectly trained problems was not a trivial one. A participant had to recognize a switch problem on a different peg than the one in training, and to rearrange the order of several moves and peg positions in which balls were placed in order to adapt the trained strategy to this new peg. Other studies involving similar indirect tasks have also succeeded in showing transfer effects (Li et al., 2008). Importantly, the transfer in the present study occurred after just a single short training session. The Li et al. (2008) study included 45 days of practice prior to testing for transfer. The process of training and the step-by-step method employed may have helped participants understand the training and apply it to a similar problem on a deeper level as compared to more holistic methods (Becic et al., 2008) or compared to extended training (Li et al., 2008).

Of particular importance for a training study is demonstrating the training for the intended population. Previous research investigating developmental differences found in strategy training have consistently shown larger effects for younger, rather than older, adults (Verhaeghen et al., 1992). The differential application of the trained strategy to two out of the three problems aids in demonstrating the importance of memory training for the older adult population. While the younger adults in the present study did demonstrate larger increases in solution time between the pre- and post-training condition, this increase was found for all problem types. The older adults, on the other hand, only showed improvements on the switch problems, those which are able to be solved using or adapting the trained strategy. This lack of increase in performance demonstrated on control problems by older adults suggests a failure to benefit either from general experience with the task or from transferring some general benefits of the training to non-switch problems. Further, it very clearly demonstrates the importance of the strategy training for the older adults, at least for short-term training.

Unlike older adults, younger adults were able to successfully apply the strategy and in addition improve on the control problems. This developmental difference between age groups could be due to several factors. First, younger adults may have self-generated a strategy which allowed for faster problem solving. Previous research has demonstrated that younger adults naturally choose optimal strategies (Becic, Boot, & Kramer, 2008) and are more likely to generate self-developed optimal strategies as compared to older adults. Secondly, older adults may have shown poor performance on the control problems because of a misapplication of the trained strategy. It is possible that the older adults were attempting to apply the strategy to the control problems resulting in a longer solution time on these problems alone. This is an unlikely outcome, however, as the older adults also did not show increases in the proportion of correctly solved control problems which is unrelated to longer problem solving. Thus, even if the older adults did initially attempt to apply the strategy to the control problems, this would only result in a longer solution time rather than an incorrect response. Additionally, the strategy training included identification of the directly trained problems so as to avoid a misapplication to the control problems. It is possible that the older adults found the task very difficult and performance on the pre-training session reached an asymptote of performance. Training on the switch problems promoted increased performance on only the trained problems. Thus, strategy training on this paradigm can be considered to be more beneficial and more critical for the older than the younger adults.

Changes in the Theta Frequency Across the Lifespan and the Impact of Strategy Training

Theta as a marker of cognitive effort has been well established in previous research on working memory tasks (Ragavachari et al., 2005; Onton et al., 2005; Mizuhara et al., 2004; Sauseng et al., 2004; Grunwald et al., 1999). In the current study, the older adult group had significantly less theta power as compared to the younger adults, both during the rest and TOL problem solving epochs. This suggests the older adults were less effective or less focused in their cognitive effort during the entire task situation. Previous research conducted with older adults during cognitive tasks have also shown decreased theta power, particularly in the frontal midline region (Cummins et al., 2007; McEvoy et al., 2001). Since this FM-theta has been found to be primarily generated in the frontal lobes it suggests this region may be beginning to show less effective or aberrant functioning in the older adult group, a view consistent with a variety of other evidence (Onton et al., 2005; Gunning-Dixon et al., 2003; Davis et al., 2009).

There may also be another view relevant to these age differences. It is possible that this decrease in FM-theta in the older adults may additionally be attributed to a shift in reliance on somewhat different brain structures. If this were the case, however, the older adult group would have shown increases in other regions during problem solving (e.g. parietal), a finding that was not supported here. However, the current analysis was necessarily limited in spatial scope, and future work should include larger topographical observations across the brain to investigate this possibility (though imaging research looking at the entire brain has not supported this suggestion; Nyberg, et al., 2003).

A unique aspect of the current study was the ability to investigate the changes in theta after strategy training, something which has not been previously investigated. In the post-training session, both younger and older adults demonstrated increases in theta power in the frontal but not parietal regions. Since the trained strategy employed here was primarily a frontally-driven, top-down processing strategy, the differential increase in the frontal regions fits well in having increases in task relevant regions in the post-training condition (Westerberg et al., 2007; Olesen et al., 2004). The older adult group was found to show larger increases in the post-training session as compared to the younger adults. While the older adults did not reach the theta power levels of the younger adults, following training there were substantial and significant increases in that power, particularly in the frontal regions.

In only a short, 20-minute training session older adults showed increases in theta frequency in the frontal regions. Altered frontal functioning of the theta band, as evidenced by a decrease in power, has been associated with task performance decrements (Cummins et al., 2007). The theta frequency band, over and above other frequency bands investigated, was found to be abnormally low in patients with mild cognitive impairment (MCI; Ueda, Musha, and Yagi, 2009). Training studies with MCI and Alzheimer's disease patients is scarce, as outlined in a detailed meta-analysis of behavioral interventions by van Paasschen, Clare, Woods, and Linden (2009). A preliminary study of name/face training in one MCI patient produced promising results with increases in fMRI BOLD signal found in task-relevant areas (inferior frontal regions; van Paasschen et al., 2009).

Differences in laterality have been identified in previous research investigating TOL problem solving with increased right activation in the frontal regions being previously reported (Lazeron et al., 2000). Specifically, those with better planning ability have been found to have parametrically increased right frontal activity as compared to the left suggesting a differential role of the hemispheres in problem solving (Unterrainer et al., 2004). In the present study, both younger and older adults were found to have greater right hemisphere theta power as compared to the left hemisphere in the pre- and post-training conditions, but the increase in theta following training older adults was in the *left* frontal regions. This could be interpreted as older adults engaging bilateral frontal regions to assist with the newly learned strategy. Older adults have been found to show bilateral activation in tasks which younger adults only show lateral activity, known as the HAROLD model (Hemispheric Asymmetry Reduction; Cabeza, 2002). This increased activation has been interpreted as compensatory as those older adults who engage bilateral regions also demonstrated better performance on the task (Cabeza, 2002). This fits well with the behavioral data which shows older adults are greatly benefiting from the strategy training.

Few differences in power or topography of theta activity were evident between problems types after training. One possible suggestion is that the increase in theta power in the post-training session was due to continued task exposure rather than an increase specific to the strategy training. Such an effect was demonstrated in previous research that had extended practice on a working memory task and found increased theta without a specific strategy being taught (Gevins et al., 1997). A second possible suggestion is that the post-training session problem-solving was attenuated by participants checking each problem, regardless of type, to see if the strategy could be applied. Nonetheless, the differential increase found in the frontal but not parietal regions would suggest that the increase is not merely a general process resulting from the continued exposure to the task because completion of the task requires both frontal and parietal involvement. The application of the strategy, however, can be argued to be a more frontally-driven cognitive process. The similar increase in the rest epoch does not consistent with this theoretical claim, though it could be suggested that participants are reviewing the strategy during the rest epoch in preparation of the upcoming trials. Regardless, the behavioral data, if not the theta findings, for both the younger and older participants clearly demonstrates differential improvement on the problem types showing that different cognitive processes were underlying problem solving of the different problem types. While the participant may have been differentially applying the strategy to certain problems this was not able to be differentiated in the theta power. Thus, while the theta band was unable to differentiate strategy application, the behavioral data demonstrates the application of the strategy to the different problem types.

One additional issue that arises in the reported findings is the lack of the anticipated increase in theta from the rest to TOL problem solving epochs in the older adult group. Increases in theta power from the rest to task conditions has been previously reported, suggesting a difference in the presented task and those previously conducted (Cummins et al., 2007; McEvoy et al., 2001). The task given in this study was considerably more difficult than the tasks previously studied (n-back tasks of reasonably easy difficulty) which may have impacted the way in which the older adults approached the task. Additionally, the current task has participants solving a problem over a long period of time where other tasks are more quickly completed. The drawn out problem solving time period may have washed out effects or smeared effects across the solving period. The task employed in this study was clearly found to be difficult for older adults, as indicated by their longer solution times and low proportion correct scores on the pre-training session as compared to the post-training session. In previous studies, older adults have evidenced a lack of increase in frontal theta power on more difficult levels while younger adults show increases in theta power with more difficult cognitive levels (Cummins et al., 2007). Similarly, older adults in a difficult reading task were found to have of less of an increase in the most difficult condition as compared to easier conditions (Persson et al., 2007). These failures to show any increase in task-relevant regions for more difficult problems has been interpreted as a breakdown in cognitive control as the task becomes too difficult. Interestingly, older adults were found to show increases in theta power in the post-training condition. This may be due to better cognitive control with the aid of the strategy. To take this into account, future research with older adults should administer a variety of difficulty levels to understand the lack of increase during the most cognitively challenging condition. Cognitive training on the most difficult conditions may also help to shed light on the impact of the training on the brain activity.

Changes in the Alpha Frequency Across the Lifespan and the Impact of Strategy Training

Past research on the alpha frequency band has reported that different aspects of processing is based on the lower or upper limits. The upper alpha frequency band has generally been depicted as being involved in visual processing and found to be primarily in the occipital/parietal regions (Gevins et al., 2000). As expected, the upper alpha frequency band in the current study did not show age-related or task-related changes during rest or TOL epochs. Previous research has also found that the upper alpha frequency band did not show age-related changes across the lifespan (McEvoy et al., 2001). This suggests a similar functional identity for the upper alpha frequency band across the lifespan.

The lower alpha frequency band has been found to increase during cognitive tasks and have a functional role during working memory tasks (Gevins et al., 2000). Present research showed an interesting change in topography across rest and TOL epochs, which suggests a functional role of the lower alpha frequency band for the younger adult group. In the rest condition, larger lower-alpha values were found at the parietal as compared to the frontal region. In contrast, during the problem presentation epochs, larger alpha power was found at the frontal as compared to the parietal regions. This topographic shift of the lower alpha band to functionally relevant regions during TOL problem solving suggests functional indexing of the problem solving process. Sauseng and colleagues note a similar shift of the lower alpha frequency band to functionally relevant regions during the task as compared to the rest condition (Sauseng, Klimesch, Schabus, et al., 2005). In their task, younger adults were found to have increases in frontal alpha power during a difficult working memory task. This work suggests a more functional role of alpha, at least during a difficult planning task. Further, this finding is not consistent with the claim that alpha is representative of “brain idling” or inhibiting non-task relevant regions (Jensen et al., 2002). Lower alpha can be seen as indicative of functional involvement of portions of the brain in task-relevant processes. The differences in the rest epoch between the younger and older adults could be attributed to different preparation styles between these groups. It is possible that older adults were more actively anticipating the next TOL problem which resulted in larger frontal alpha involvement during the rest epoch.

An Integrative Look at the Theta and Alpha Frequency Bands and Its Impact Across the Lifespan

The results of the present study and previous sections of discussion focusing separately on the theta and alpha bands have demonstrated both similarities and differences across these frequency bands. As with the theta frequency band, the lower alpha frequency band had increases in the post-training condition suggesting a functional role of the underlying regions as increases in activity that have been previously reported were interpreted as compensatory activity (e.g. Westerberg et al., 2007). Unlike the theta frequency band, alpha power values were found to be similar across age groups in both the frontal and parietal regions. An integrated evaluation of these will help to clarify the different functional roles of these bands during working memory tasks.

An interesting theoretical model proposed by Klimesch and colleagues suggests complementary roles of the theta and alpha frequency bands, with each being associated with different aspects of memory and cognitive processes (Klimesch et al., 2009). The model suggests that the alpha frequency band is associated with the processing of a “knowledge system,” a construct that describes general processing of meaningful stimuli. The theta frequency band is argued to reflect processing associated with “working memory,” a construct used to describe controlled access to new information. Under this model, these two memory systems are integral to memory processes and are integrated through a larger network which can be studied by investigating the alpha and theta frequency bands. The importance of this theoretical model rests on the integrative nature of the different frequency bands working in unison across the brain.

One way to measure this interaction among brain regions or the combined effort of several regions across the brain is looking at the coherence values in different frequency bands. For example, during task completion the theta frequency band has been shown to increase in coherence between the frontal and parietal regions (Sauseng, Klimesch, Schabus, et al., 2005). Alpha, in the same light, demonstrates increases in coherence across widespread regions. Based on this model, the importance of a single region is diminished as a more integrative role across the brain is identified for task completion.

Though the current study did not employ methods which investigate coherence across regions of interest, the power values obtained at the frontal and parietal regions are consistent with this theoretical model. The theta frequency band was found to increase in the post-training session which involved increased use of working memory processes. The application of this model would suggest that power values measured at one region may reflect processing happening at that region or processing happening among several regions. As demonstrated in fMRI work, the completion of a task heavily relies on many regions for completion (e.g., Lazeron et al., 2000).

The decrease in FM-theta observed across the lifespan and in previous work (Cummins et al., 2007; McEvoy et al., 2001) may be indicative of frontal breakdown *or* possibly due to a widespread deterioration of long-range communication across the brain. A compelling analysis of this idea was suggested by Greenwood (2000) in which work was presented to show all regions of the brain are demonstrating deterioration as humans age and that not only the frontal regions are affected by time. This idea is presented to demonstrate the importance of further work in coherence analysis across the entire brain. Diffusion tensor imaging work has demonstrated a clear decrease in structural connectivity in older adults, supporting the suggestion of widespread neural breakdown (Venkatraman, et al., 2009). While work has shown this widespread breakdown, it is currently unknown what the impact of training is on this neuronal network. A coherence analysis of the theta and alpha frequency bands in a pre- and post-training design would provide valuable information to help understand these localized increases and how this changes across the lifespan.

Impact of Individual Differences in Processing Speed on Behavior and EEG

The task employed to measure processing speed, the digit symbol task, has been commonly used to measure this construct in previous research (e.g., Venkatraman, et al., 2009; Ball, Edwards and Ross, 2007; Joy, Kaplan and Fein, 2004; Verhaeghen and Marcoen, 1996). Individual performance on the digit symbol task has been found to be a predictor in strategy application (Kliegl, Smith, and Baltes, 1990). It is thought that the ability to quickly process information will have an impact on the ability to acquire a new strategy. Kliegl et al. (1990) trained younger and older adults on a serial recall task demonstrated differential ability to apply the strategy with the digit symbol score becoming more important as training progressed. The digit symbol score did not correlate with pre-training performance but only emerged as a significant predictor as training continued. This was interpreted as the importance of processing speed becoming more influential as the application of the strategy was attempted.

In the current study, the younger adults did not demonstrate behavioral differences between the LPS and HPS groups, whereas older adults did do so suggesting the role of processing speed or the application of the strategy to the TOL was not the same in the younger and older adult groups. It is possible that the younger adults did not find this task overly challenging and thus regardless of initial ability, application of the strategy to the trained problem did not tax the younger adults. Consistent with this, even in the pre-training session the younger adult group was solving nearly all problems correctly. For the older adult group the impact of processing speed was only found to be a factor on the indirect problems. Contrary to expectations, the LPS older adults were more likely to transfer the strategy to the indirect problems as compared to the HPS older adults. The LPS and HPS older adults did not differ in level of performance on the task in the pre-training session showing that the LPS group did in fact show more improvement in the post-training condition. A further inspection of individual change scores for each problem type showed that while all older adults are improving on the direct problems, four older adults in the HPS group were not improving on the indirect problems. If those four older adults are removed from the analysis, both the LPS and HPS older adult groups have similar improvement on the indirect and direct problem types. It is surprising that the four older adults who are not able to transfer the strategy are in the HPS group, though other cognitive factors not relating to processing speed may be interacting with the ability to apply and transfer a strategy. Both processing speed groups showed similar performance gains for the direct problems in the post-training session.

Individual differences in working memory capacity have been found to affect electrophysiological signals in adults (Gevins et al., 2000; Nittono, Nageishi, Nakajima, and Ullsperger, 1999). For example, when Gevens and Smith (2000) divided younger adults by scores on a test of general cognitive ability clear differences in FM-theta frequency band were found. The high-performing younger adults showed greater increases in FM-theta with increased task exposure while the low-performing younger adults showed no increase across task exposure. This was interpreted as the high-performing younger adults showing greater ability to sustain attention and allocate resources. Thus, these high performing younger adults were showing greater cognitive control as compared to the other groups. In the current work, processing speed ability was found to be an important factor in EEG signatures.

The theta frequency band illuminated several interesting differences between the LPS and HPS groups. The HPS older adults were found to have similar EEG topography to the younger adults. This was found in the midline lead analysis in which the HPS older adults showed larger FM-theta as compared to the LPS older adults. While the HPS older adults had lower FM-theta as compared to the younger adults group they were more similar in power and topography as compared to the LPS older adults. Additionally, both younger and older HPS groups showed larger right frontal theta activity as compared to the LPS groups.

Given the differences in EEG processing between the LPS and HPS older adults, it is surprising that the HPS older adults do not show correspondingly better TOL behavioral performance as compared to the LPS older adults. There are several possible reasons for this lack of performance difference between these groups. First, as noted earlier, it is possible that the task is very difficult and this masks the more efficient problem solving, as evidenced by increased brain activity, in the HPS older adults. Further examination of this finding with problems of varying difficulty level would be a way to investigate this possibility. Secondly, individual differences in processing speed and its effect on brain activity may not be involved in the problem solving process. Thus, while HPS older adults show more FM-theta and increased right activation that is indicative of better problem solving ability, this may not be seen in the performance measures studied here. These HPS older adults may be applying more efficient strategies or "catching on" to the strategy quicker, something not investigated in the current study. Future research should strive to investigate the changes in performance and EEG across the pre- and post-training session to understand differences in learning rates, which may be different across these processing speed groups. In support of this, the Kliegl study demonstrated that the effect of individual differences in processing speed was only evident in the later stages of training as compared to the beginning (Kliegl et al., 1990). The collapse of these measures across blocks of trials within a session may be masking a behavioral difference[5].

The lack of findings in the lower alpha frequency band between LPS and HPS groups indicates that the underlying cognitive functions associated with the lower alpha frequency band are not affected by processing speed. As described above, the functional role of alpha is associated with the processing of meaningful stimuli, a cognitive process possibly not affected by processing speed.

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[5] This analysis could not reasonably be carried out for the current study as the number of trials needed to compute the EEG frequency measures was too small to allow for additional separation across time.

Clearly, future work investigating processing speed as an important predictor of strategy application and EEG signatures would be a valuable extension of this work. First, performance on the measured task should be investigated in several ways, including more advanced cognitive constructs, such as problem solving efficiency or rate of learning abilities. Additionally, coherence measures of neural networks across the brain may yield differential efficiency and widespread processing in the HPS groups, as did the power analysis conducted in the current study.

Implications, Suggestions for Future Research and Conclusion

The inclusion of physiological measurements in future strategy training research supplies critical information to the understanding of the underlying changes accompanied with strategy training. This is especially important when investigating changes in aging populations, as the underlying structural regions involved are damaged more so than in younger populations. The way in which underlying neural regions respond to training may vary depending on the degree of breakdown due to age or disease. This would be expected, of course, since systems severely damaged have been found to behave differently as compared to intact systems (e.g., Prvulovic, Van de Ven, Sack, Maurer, & Linden, 2005). Additionally, different types of strategic training may be associated with differing post-training activity differences. An increase in efficiency may be associated with an increase in the task-relevant regions. A strategy in which participants use a different set of cognitive abilities would possibly result in different regions becoming active (Jonides, 2004). Additionally, measures of coherence across brain regions and widespread neuronal interaction may help to pinpoint other regions of decline across adulthood as well as the type of decline. An understanding of the changes in the neural systems across the brain may aid in tailoring the cognitive intervention to tap regions less affected by aging. The integration of physiological methods in behavioral training research can help to identify what is actually changing in the post-training condition.

As evidenced in the current study, a more step-by-step approach may aid in the transfer of the learned strategy to new problems. An approach similar to this step-by-step training, goal management training (GMT), has been applied effectively in both normal and clinical populations with excellent success (van Hooren, Valentijn, Bosma, Ponds, van Boxtel, Levine, et al., 2007). The theory of GMT is that any activity requires a list of actions to complete until the goal in achieved. Similarly, the strategy training employed in the current study concentrated on participants understanding the step-by-step actions needed to take in order to reach the goal. While the GMT method of training was originally designed for brain injured patients (Levine, Robertson, Clare, Carter, Hong, Wilson, et al., 2000), its application to normal populations has demonstrated its use in everyday life (van Hooren et al., 2007). In a study which employed GMT, younger and older adults received step-by-step instructive training on several executive function measures (Levine et al., 2000). Outcome measures of ability to perform day to day activities showed that the trained group far exceeded the performance of the wait-list control group. It is suggested that the step-by-step procedure of the training aided in increased performance in the elderly.

Through innovative research and clear goals on the future of aging research, training paradigms that impact the lives of older adults can become a reality. Through dedicated researchers, the lives of older adults can be impacted and the last years of life can be associated with independence, growth and sustainability.

APPENDIX A

LIST OF TOWER OF LONDON PROBLEMS

Problem numbers refer to the number designated in Berg and Byrd (2002).

Problem Number	Difficulty Level	Problem Type
Block 1		
23:32	5	tall switch
26:44	5	middle switch
26:64	6	Control
22:32	6	tall switch
22:52	5	Control
24:66	5	middle switch
Block 2		
56:14	6	Control
22:33	5	tall switch
56:34	5	middle switch
22:52	5	Control
26:56	6	middle switch
53:42	5	tall switch
Block 3		
56:26	6	middle switch
52:43	5	tall switch
62:22	5	Control
54:16	5	middle switch
62:22	5	Control
52:42	6	tall switch
Block 4		
33:22	5	tall switch
36:54	6	Control
36:14	5	middle switch
32:22	6	tall switch
34:56	5	middle switch

Problem Number	Difficulty Level	Problem Type
Block 5		
32:62	5	control
36:66	6	middle switch
32:23	5	tall switch
16:34	6	control
13:62	5	tall switch
16:54	5	middle switch
Block 6		
14:36	5	middle switch
12:42	5	control
12:62	6	tall switch
16:46	6	middle switch
12:63	5	tall switch
12:42	5	control
Block 7		
43:52	5	tall switch
46:64	5	middle switch
46:24	6	control
42:52	6	tall switch
42:12	5	control
42:26	5	middle switch
Block 8		
42:12	5	control
42:53	5	tall switch
46:16	6	middle switch
66:44	6	control
66:24	5	middle switch
Block 9		
64:46	5	middle switch
62:12	6	tall switch
62:32	5	control
66:36	6	middle switch
62:32	5	control
62:13	5	tall switch

APPENDIX B

CORRELATIONS BETWEEN BEHAVIORAL VARIABLES

	Variable Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Pre-Training																		
1	Control PC	1.000	.695**	.778**	-.019	.449*	.341	.188	-.146	.063	.757**	.812**	.740**	.268	.233	.109	.210	--	--
2	Indirect PC	.309	1.000	.814**	.079	.411*	.102	.223	-.357*	.005	.680**	.846**	.722**	.264	.045	.070	.181	--	--
3	Direct PC	.105	.774**	1.000	-.103	.327	.274	.313	-.229	-.191	.766**	.833**	.739**	.184	.097	-.041	.229	--	--
4	Control ST	-.064	-.034	-.087	1.000	.664**	.548**	.379*	.317	.280	-.102	.043	-.051	.757**	.437*	.341	.177	--	--
5	Indirect ST	-.287	-.402	-.446*	.663**	1.000	.704**	.391*	.124	.247	.321	.382*	.313	.658**	.441*	.296	.212	--	--
6	Direct ST	-.073	-.306	-.410*	.517**	.813**	1.000	.483**	.414*	.081	.222	.280	.220	.558**	.568**	.348	.121	--	--
7	Control NR	-.138	-.026	.090	.079	.317	.391	1.000	.019	.171	.135	.297	.146	.356*	.268	-.028	.159	--	--
8	Indirect NR	.041	-.514*	-.655**	.353	.551**	.620**	.194	1.000	.250	-.156	-.244	-.189	.312	.123	-.040	-.161	--	--
9	Direct NR	.117	-.584**	-.795**	.227	.534**	.500*	.050	.696**	1.000	-.031	-.084	.022	.466**	.178	.161	-.161	--	--
	Post-Training																		
10	Control PC	.227	.319	.390	-.223	-.433*	-.513*	-.152	-.531**	-.274	1.000	.820**	.794**	.239	.170	.054	-.001	--	--
11	Indirect PC	.473*	.671**	.446*	-.043	-.374	-.338	-.158	-.467*	-.289	.653**	1.000	.866**	.262	.159	-.007	.155	--	--
12	Direct PC	.153	.496*	.418*	.056	-.257	-.257	-.451*	-.346	-.315	.522**	.658**	1.000	.208	.100	.128	.217	--	--
13	Control ST	-.316	-.212	-.163	.434*	.676**	.609**	.269	.421*	.212	-.346	-.189	.018	1.000	.633**	.382*	-.012	--	--
14	Indirect ST	-.053	-.222	-.403	.143	.482*	.552**	.177	.569**	.296	-.409*	-.276	-.387	.440*	1.000	.628**	-.049	--	--
15	Direct ST	-.089	-.332	-.416*	.136	.526**	.711**	.207	.565**	.405*	-.498*	-.520**	-.489*	.468*	.830**	1.000	-.033	--	--
16	Control NR	.082	-.219	-.255	.077	.422*	.480*	.342	.609**	.396	-.650**	-.433*	-.351	.499*	.443*	.532**	1.000	--	--
17	Indirect NR	.000	-.444*	-.506*	.359	.443*	.406*	.243	.708**	.501*	-.387	-.458*	-.467*	.294	.592**	.538**	.485*	1.000	
18	Direct NR	.000	-.391	-.446*	.146	.396	.287	.458*	.689**	.397	-.372	-.401	-.630**	.273	.652**	.454*	.531**	.718**	1

Abbreviations: PC = proportion correct; ST=solution time, NR=proportion of no response
Young adult only correlations on top portion of table, Older adult only correlations on lower portion of table
** = p<.001; * = p <.01

	Variable Name	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
	Pre-Training																		
1	Control PC	1.00	.542	.480	-.018	.114	.162	.013	.038	.130	.545	.691	.503	.007	.062	.019	.106	.009	.010
2	Indirect PC	.688**	1.00	.793	.039	.029	-.087	.081	-.356	-.326	.540	.784	.633	.046	-.103	-.152	-.093	-.267	-.234
3	Direct PC	.668**	.856**	1.00	-.080	-.065	-.089	.181	-.452	-.541	.600	.676	.599	.026	-.210	-.253	-.124	-.340	-.298
4	Control ST	-.446**	-.358**	-.467**	1.00	.649	.502	.152	.267	.164	-.137	.019	-.001	.548	.212	.154	.046	.258	.100
5	Indirect ST	-.411**	-.393**	-.487**	.840**	1.00	.757	.309	.400	.404	-.021	.065	.016	.645	.438	.415	.320	.347	.309
6	Direct ST	-.395**	-.461**	-.505**	.777**	.902**	1.00	.389	.523	.369	-.131	.008	-.042	.553	.524	.586	.377	.335	.231
7	Control NR	-.352**	-.259	-.231	.507**	.613**	.657*	1.00	.135	.021	-.013	.055	-.210	.261	.177	.135	.292	.210	.404
8	Indirect NR	-.314*	-.547**	-.632**	.553**	.640**	.706*	.419**	1.00	.650	-.320	-.273	-.248	.320	.470	.450	.557	.684	.666
9	Direct NR	-.289*	-.543**	-.706**	.526**	.672**	.657*	.373**	.767**	1.00	-.136	-.142	-.190	.162	.231	.319	.347	.483	.379
	Post-Training																		
10	Control PC	.698**	.676**	.730**	-.476**	-.437**	-.500*	-.336*	-.529**	-.427**	1.00	.760	.687	-.021	-.156	-.240	-.376	-.230	-.221
11	Indirect PC	.779**	.841**	.767**	-.344**	-.347**	-.384*	-.256	-.474**	-.401**	.824**	1.00	.786	.078	-.072	-.246	-.193	-.240	-.209
12	Direct PC	.589**	.689**	.661**	-.254	-.262	-.301	-.368*	-.390**	-.356**	.732**	.814**	1.00	.110	-.206	-.269	-.198	-.305	-.411
13	Control ST	-.506**	-.422**	-.481**	.807**	.868**	.841*	.608**	.610**	.578**	-.472**	-.378**	-.239	1.00	.462	.392	.365	.231	.212
14	Indirect ST	-.464**	-.482**	-.577**	.665**	.786**	.823*	.561**	.679**	.599**	-.524**	-.440**	-.400**	.824*	1.00	.800	.370	.536	.588
15	Direct ST	-.517**	-.524**	-.612**	.669**	.796**	.858*	.563**	.669**	.652**	-.579**	-.537**	-.433**	.827*	.935*	1.00	.457	.503	.420
16	Control NR	-.279*	-.369**	-.419**	.434**	.606**	.638*	.530**	.697**	.573**	-.573**	-.422**	-.355**	.641*	.640*	.682*	1.00	.475	.522
17	Indirect NR	-.241	-.423**	-.491**	.455**	.515**	.508*	.395**	.745**	.597**	-.400**	-.392**	-.405**	.455*	.617*	.584*	.588**	1.00	.717
18	Direct NR	-.214	-.378**	-.438**	.324*	.463**	.417*	.517**	.717**	.500**	-.372**	-.349**	-.487**	.411*	.615*	.511*	.606**	.758*	1.00

Abbreviations: PC = proportion correct; ST=solution time, NR=proportion of no response
Age partial correlations with Younger and Older Adults on top portion of table, All participants together, no age partial on lower portion of table
** = p<.001; * = p <.01

APPENDIX C
SIGNIFICANT FINDINGS FROM BEHAVIORAL, EEG, AND PROCESSING SPEED ANALYSES

Significant effects are listed below for each type of analysis completed.

	Main Effects			Interaction		
Behavioral						
Proportion Correct	Age Session PT			--		
Change Score	Age			--		
Solution Time	Age PT			Age*Session*PT Age*Session Session*PT		
Change Score	Age			Age*PT		
Proportion of No Responses	Age Session PT			Age*Session*PT Age*Session Age*PT		
EEG						
	Rest	P.P.	P.C	Rest	P.P.	P.C
Theta Fz-Pz	Age Lead	Age Session Lead	Age Lead	Session*Lead	Session*Lead Age*Lead	Session * PT * Lead Session*Lead Age*Lead
Theta FC3-FC4	Age Lead	Age Session Lead	Age Session Lead	--	Age*Session*Lead	Session*PT
Lower Alpha Fz-Pz	Session	Lead	Session Lead	Lead*Age	--	--
Processing Speed Groups						
Solution Time	--			--		
Change Score	--			Age*PT *PSG		
	Rest	P.P.	P.C	Rest	P.P.	P.C
Theta Fz-Pz	--	--	--	Age*Lead*PSG	Age*Lead*PSG	Age*Lead*PSG
Theta FC3-FC4	--	--	--	Lead*PSG	Lead*PSG Session*PSG*PT	Lead*PSG Session*PSG*PT
Lower Alpha Fz-Pz	--	--	--	--	Session*Lead*PSG	--

Note: Problem presentation (P.P.); Problem completion epoch (P.C.); Processing speed group (P.S.G.); Problem type(P.T.)

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BIOGRAPHICAL SKETCH

Kimberly was born in Ipswitch, Massachusetts and raised in Miami, Florida. After high school, Kimberly attended the University of Florida to pursue her undergraduate degree in psychology. During her time at UF, Kimberly worked in several laboratories on studying cognition, development and neuropsychology. After working in Dr. William Keith Berg's laboratory for several months, Kimberly decided to stay at UF to continue her study of neuropsychological development. Kimberly's graduate research focused on children, with and without Attention Deficit Hyperactivity Disorder (ADHD), and the developmental spectrum of planning and learning until adulthood. During her study at UF, Kimberly became interested in the later aspects of development, specifically ways to improve the declining memory and planning abilities of older adults. This change in focus has helped her to more fully understand the changes that occur throughout life, why those occur, and its impact on different ages.

Kimberly hopes to continue her work in older adult memory and cognition improvement by becoming more involved in research with Alzheimer's disease and mild cognitive impairment. These two devastating diseases often claim the last years of a person's life and only through intense research and medical practice can they be alleviated.

In her spare time, Kimberly enjoys reading and spending time with the love of her life, Christopher Case. The lovebirds reside in Gainesville, Florida in their first home.