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The Relationships Among Age, Physical Activity, and Working Memory

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THE RELATIONSHIPS AMONG AGE, PHYSICAL ACTIVITY, AND WORKING MEMORY

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ABSTRACT

RELATIONSHIPS AMONG AGE, PHYSICAL ACTIVITY, AND WORKING MEMORY

Ellen M. Carpenter
Old Dominion University, July 2008
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As our population ages, determining exogenous factors that may offset cognitive decline become increasingly important. The primary goal of the present study was to determine whether older individuals who engage in regular physical activity demonstrate superior working memory performance relative to older sedentary individuals. Forty young (20 active, 20 sedentary) and forty older (20 active, 20 sedentary) individuals engaged in cognitive measures of information processing speed, inhibitory function, and verbal and visuospatial working memory. Age differences in recall were found for verbal and visuospatial span tasks, as well as for recall reaction time on verbal and visuospatial n-back tasks, and age-related performance decrements were exacerbated in the most difficult task conditions. All participants performed less accurately and took longer to respond to stimuli as the verbal and visuospatial n-back tasks became more difficult. A second objective was to examine the effects of age and physical activity on frontal midline theta and hemispheric alpha, as a function of verbal and visuospatial n-back task difficulty. Frontal midline theta recorded at Fz increased for all participants as taskload increased for the verbal, but not visuospatial n-back task. However, as the visuospatial task became more difficult, the younger group showed a greater increase in frontal midline theta than the older group. Neither age, physical activity, nor taskload had an effect on frontal and parietal alpha asymmetry as analyzed from recordings at F3, F4, P3, and P4. The third objective was to evaluate the degree to which physical activity was related to information processing speed and inhibitory function in older adults, as these two constructs are associated with working memory. Cognitive processing speed, attention accuracy, and attention reaction time were all influenced by age. The hypothesized interaction between age and physical activity was not observed for any of the behavioral nor physiological measurements. Several possible explanations for why the main predictions were not supported are discussed, including the idea that it may be physical fitness, rather than physical activity, which contributes to healthy adult brain aging.

This dissertation is dedicated to my family.

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And finally, Chuck, thank you for being the wind beneath my wings.

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INTRODUCTION

An increasing amount of research suggests a beneficial relationship between physical activity and cognitive function in older persons (Colcombe & Kramer, 2003; Etnier, Salazar, Landers, Petruzello, Han, & Nowell, 1997; Kramer, Colcombe, & McCauley, 2005; Kramer, Hahn, Cohen, Banich, McAuley, & Harrison, 1999; Newson & Kemps, 2006; Spirduso, 1975, 1980). These findings are of considerable value, as a substantial body of literature suggests that cognitive function declines with age for a large percentage of older adults (Birren & Schaie, 1996; Craik & Byrd, 1982; Park & Schwarz, 2000; Salthouse, 1991). It is therefore important to identify behavioral factors that may attenuate this decline, and it appears that engaging in physical activity may be such an exogenous factor. However, scholarly inquiry must go beyond the identification of such a relationship. An equally important question is to investigate in what manner does exercise impact cognitive function? One reasonable approach is to look at the link between exercise and working memory. Working memory is tied directly to higher cognitive processes (Baddeley, 1994; Engle, 2002; Kyllonen & Cristal, 1990; Salthouse, 1990), and studies abound to confirm the existence of age-related differences in working memory (Babcock & Salthouse, 1990; Hasher & Zacks, 1988; Kliegl, et al., 1994; Reuter-Lorenz, et al., 2000; Verhaeghen, Marcoen, & Gossens, 1992). Thus, an important question to pose is whether physical activity affects working memory. One way to answer this question is to compare the performance and electrophysiological responses of sedentary and active older individuals on laboratory tasks of working memory.

This dissertation adheres to the journal style specifications of *Psychology and Aging*.

A related approach is to examine which theory of cognitive aging best explains the relationship between exercise and the maintenance of working memory. Is it that physical activity forestalls the slowing of information processing that generally accompanies aging? Or is it perhaps that attentional mechanisms remain intact as a function of fitness?

Before the relationship between physical activity and working memory in the older adults can be addressed, it is first necessary to discuss both cognitive aging and working memory in general, and then specifically examine the impact of age on working memory.

Cognitive Aging

The term cognitive aging refers to the natural decline in cognitive functioning that accompanies otherwise "normal" healthy aging. In general, performance on speed of processing, working memory, and recall tasks shows a linear decline across the life span, whereas measures of acculturated knowledge, or crystallized intelligence, do not show age-related declines (Park, et al., 1996). Additionally, performance on many tasks involving attention, problem solving, and reaction time declines with age (Birren & Schaie, 1996; Salthouse, 1991; Zacks, Hasher, & Li, 2000). Evidence for cognitive aging comes not just from laboratory experiments, but also anecdotally as aging adults tackle everyday challenges such as learning new technology, driving in unfamiliar environments, and managing medications and finances (Park & Jones, 1997; Park, Nisbett, & Hedden, 1999). Comments about forgetfulness, not feeling mentally sharp, or lacking mental energy reflect a self-awareness that certain necessary mental resources are lacking. This decline in cognitive function easily affects personal well-being and may increase the likelihood of nursing home entry. Besides the humanitarian interest in keeping our senior citizens at a high level of cognitive functioning, there are important societal and financial reasons of concern, as suggested by the following statistics. In 2003, persons over age 65 numbered 35.9 million, which represented 12.3% of the U.S. population. It is projected that by 2030, membership in this age group will almost double to 71.5 million older individuals, or 20% of the U.S. population (Federal Interagency Forum on Aging-Related Statistics, 2004). These numbers certainly underscore the importance of understanding the structural and functional changes in the aging brain, as well as identifying exogenous variables that may impact the rate of cognitive decline.

The human brain undergoes several significant structural changes as a result of aging. Raz (2000) also reports a small, but persistent reduction in brain weight (2% per decade). Computerized tomography (CT) studies show that normal aging is associated with the expansion of cerebral ventricles and generalized enlargement of the cerebral sulci. Aging is accompanied by significant structural alterations of neurons, which are the basic elements of the central nervous system (CNS). Neuronal connectivity changes in the brain as a result of aging. This connectivity may be thought of as perhaps the most plastic aspect of the adult CNS. Both selectively and regionally, there is a decline in synaptogenesis and neurons debranching of the dendritic arborization (Anderson & Rutledge, 1996). Physiological changes include moderate reductions in regional cerebral bloodflow (CBF), cerebral metabolic rate of oxygen utilization, and gray matter blood volume (Madden & Hoffman, 1997).

The structural approach suggests a patchwork pattern of differential decline and relative preservation of the structure and physiology of the brain as individuals age. For example, the prefrontal cortex (PFC), an area essential for executive functioning, generally receives a greater negative impact from aging (Raz, 2000). Other areas, such as the hippocampus, cerebellum, and the temporal, parietal, and occipital cortices show greater resilience to aging. This gradient of differential vulnerability seems to follow the rule "last in (phylogenically, ontogenetically), first out" (Raz, 2000, p. 37).

It was beyond the scope of this study to compare the structural and physiological integrity of active and sedentary older individuals' brains. Rather, the present study aims to investigate the *functional* changes that occur in the aging brain, and how these may differ between groups of older sedentary and physically active individuals. As the term implies, a functional perspective seeks to identify changes in how the brain processes information as a result of aging. It is widely believed that cognitive aging occurs due to deficits in processing resources (Craik & Byrd, 1982). Four processing resources have been hypothesized to explain age differences in cognitive functioning. They are: (a) sensory function, (b) working memory (c) information processing speed, and (d) inhibitory function. It is important to bear in mind that although each of these mechanisms has been shown to account for age-related variance on cognitive task performance, it is also possible, and indeed, very likely, that they may work in combination. A brief overview of each of these theories follows.

Sensory function. Recent correlational studies (Lindenberger & Baltes, 1994, 1997) have underscored an important relationship between sensory and cognitive function in aging. Using a sample of participants ranging in age from 25 to 103, Lindenberger and Baltes (1997) demonstrated that nearly all of the age-related variance on speed of processing, reasoning, memory, world knowledge, and verbal fluency could be accounted for by differences in visual and auditory acuity. Several theoretical frameworks have been advanced to account for the covariation of perceptual and cognitive decline. Hypotheses include sensory deprivation, common-cause, cognitive load on perception, and information-degradation (see Schneider & Pinchora-Fuller, 2000, for a more in-depth explanation of these alternative hypotheses).

Working memory. Working memory has also been considered a processing resource that diminishes with age (Salthouse, 1990). The ability to simultaneously store and process information is paramount to carrying out higher level cognitive functions (e.g., executive function and memory). Decrements in this "building block" of cognition may be responsible for age-related changes in cognition in general. Older adults often have difficulty in situations where they must hold, manipulate, and integrate information over a short period of time (Park & Schwarz, 2000). Some theorists believe that a decreased ability to simultaneously store and process information is at the root of cognitive aging. An example of a real-life task that requires such ability would be a telephone tree that involves long complex sentences with several response alternatives. Difficulty with such a task might imply a decline in working memory. Baddeley (1986) has described working memory as the total amount of mental energy available to perform on-line mental operations. The dual function of both processing and storage suggests that working memory plays an important role in many cognitive tasks (Baddeley, 1986; Carpenter & Just, 1989; Salthouse, 1990). As will be presented later, the literature provides copious examples of age-related decline in working memory.

Information processing speed. Using a different approach, Salthouse (1991, 1996) argues that much of all age-related variance on cognitive tasks can be attributed to a generalized, decreased speed of performing mental operations. This reduction in speed leads to cognitive impairment because of what Salthouse termed "limited time" and "simultaneity" mechanisms. According to Salthouse, cognitive performance is degraded when processing is slow because relevant operations cannot be successfully executed (limited time), and the products of earlier processing may no longer be available when later processing is complete (simultaneity). The slowing of information processing speed theory suggests that as tasks become more difficult, greater differences will be seen between younger and older adults.

Inhibition. This model of cognitive aging suggests that deficits in cognitive function for older adults stem from an inability to inhibit irrelevant material (Hasher & Zacks, 1988). That is, attention is spread between both relevant and irrelevant information. Not only might unnecessary information gain initial entrance into working memory, mental energy is wasted in its maintenance, at the expense of allowing target information to enter. Support from this position comes from negative priming studies, in which older adults respond more quickly when a response that should have been inhibited in Trial 1 becomes the target response on Trial 2 (Hasher, Stoltzfus, Zacks, & Rypma, 1991).

While acknowledging the strong empirical support for each of these four processing mechanisms – sensory function, working memory, speed of processing, and inhibitory function- it was beyond the scope of the present study to attempt to extricate the degree to which each one explains differences in cognitive functioning between sedentary and physically active older individuals. Rather, it focused on identifying the role that physical activity plays in attenuating age-related decline in working memory. The effects of individual differences in sensory function were minimized through visual screening, and both speed of processing and inhibitory function were investigated as sources of age-related differences in working memory. The following section will first build a deeper understanding of the working memory construct, its relationship with cognitive aging, and finally, why both information processing speed and inhibitory mechanisms have been implicated in age-related declines in working memory.

Working Memory

According to Baddeley (1986), "the essence of the concept of working memory lies in its implications that memory processes play an important role in non-memory tasks" (p. 246). For example, working memory is thought to be fundamental to language acquisition, comprehension, and reasoning (Baddeley, 1996). It has also been suggested that individual differences in working memory capacity are highly related to performance on conventional measures of intelligence (Kyllonen & Cristal, 1990).

Baddeley and Hitch (1974) investigated whether a general memory system is used for all working memory tasks. In their paradigm, participants performed a digit span task while simultaneously performing working memory tasks that involved reasoning, comprehending, or learning. The digit span task required participants to remember and rehearse continuously one, three, or six random digits. The results indicated that although performance on the working memory tasks deteriorated as concurrent memory load (digit span) increased, many participants could still perform the demanding cognitive tasks. The authors took this as confirmation that the short term memory system responsible for digit span was not synonymous with a general working memory system. Rather, it provided evidence for a multi-component working memory system. They formulated a tripartite, rather than unitary, working memory system.

According to Baddeley and Hitch's model, a central executive component functions primarily as an attention controller and oversees two peripheral storage systems. An important function of the central executive is to coordinate information and regulate processes that operate on the contents of working memory. As outlined by Smith and Jonides (1999), these processes include attention and inhibition (the focus of attention on relevant information and processes and the inhibition of irrelevant ones), scheduling complex tasks, which involves the switching of focused attention between tasks, planning a sequence of subtasks, and monitoring, updating, and checking the contents of working memory. Many of these processes are highly interrelated, such as attention and inhibition and the ability to switch attention.

The central executive coordinates the functioning of two subsystems. The first subsystem is the articulatory, or phonological loop. The phonological loop itself is theorized to be comprised of a verbal store and an articulatory rehearsal loop. It is this subvocal articulatory rehearsal that permits the maintenance of rapidly decaying speech-based traces in the verbal store. Thus, the phonological loop plays an integral role in verbal working memory.

The second subsystem is the visuospatial sketchpad (sometimes called scratchpad), and it functions to hold information about objects, location, and other visual input that is not easily verbalized. Hence, it is an important component of visuospatial working memory. It too, can be further fractionated into two separate subsystems, responsible for the maintenance of "what" (visual) and "where" (spatial) information. In other words, it aids in object identity and location memory, respectively (Ungerlieder & Mishkin, 1982).

Baddeley's distinction between verbal and visuospatial working memory corresponds with theories of functional lateralization of the brain. It is generally well accepted that the cerebral hemispheres possess both anatomical and functional asymmetries (Hugdahl & Davidson, 2004). Research with animals, brain lesion patients, and neurologically intact individuals suggests that the left and right hemispheres appear to be functionally specialized (Friston, 2004). This statement should not be confused with functional localization, which implies that a function can be localized in a specific cortical area. Rather, functional specialization suggests that either hemisphere is more dominant in a particular aspect of perceptual, cognitive, or motor processing. Functional specialization is also known as functional lateralization, although it is understood that the brain is organized such that effective connectivity of brain regions is essential for integration within and among specialized areas.

Support for functional lateralization of the brain comes from neuroimaging studies. A review of positive emission topography (PET) and functional magnetic resonance imaging (fMRI) studies indicates that left and right hemisphere regions are activated by different kinds of information (Smith & Jonides, 1999). Their meta-analysis implies that: (a) storage for verbal material activates Broca's area and left hemisphere supplementary and premotor areas, (b) storage of spatial information activates the right hemisphere premotor cortex, and (c) storage of object information activates other areas, such as the dorsolateral prefontal cortex. The significance of hemispheric specialization and cognitive aging will be addressed following further explanations of techniques for measuring verbal and visuospatial working memory.

Verbal working memory. Historically, the functionality of verbal working memory has been measured via span tasks, such as forward digit and word spans. These are tasks in which the participant is asked to recall an increasingly lengthy list of digits or words. While imposing demands on storage, these tasks do not necessarily tap into processing demands, and thus may not detect individual differences in working memory. Therefore, Daneman and Carpenter (1980) developed a now classic measure of working memory (WM), called the reading or listening span. Versions of this task have been extended to computation operations (Babcock & Salthouse, 1990; Engle, 1999) and visuospatial WM through the use of matrices (Law, Morrin, & Pellegrino, 1995; Miyake et al., 2001).

Daneman and Carpenter's goal was to distinguish between structural and functional capacities in working memory. Structural capacity refers to a passive storage component, whereas functional capacity refers additionally to the active processing component of WM. Whereas digit and word spans may measure the structural capacity of WM, assessing functional capacity involves measuring an individual's capacity to simultaneously engage in ongoing processing and store recently presented information. Whether reading, listening, computing arithmetic or matrix equations, the task methodology requires the participant to verify a series of sentences, computations, or matrices, remember the final word (calculation, location) of each, and then recall these final words (numbers, locations). The number of sentences (computations, matrices) in each set is increased until an approximation of span is reached. This approach allows for the identification of individuals who are high and low in WM capacity. From here, hypotheses are tested that relate working memory to more complex cognitive functions.

For example, individual differences in WM spans can function as predictors for other tasks, such as language comprehension and reasoning tasks (Just & Carpenter, 1992). Daneman and Merikle (1996) conducted a meta-analysis to determine whether measures that tap the combined storage and processing capacities of WM or those that just tap storage capacity (e.g., forward digit or word spans) are equal predictors of reading comprehension. Their analysis included 6179 participants in 77 independent studies. They reported that the average effect size was greater for verbal processing plus storage tasks than for verbal storage only tasks. Interestingly, these differences in effect sizes between storage only and storage plus processing were replicated for math as well as verbal tasks, suggesting that both math and verbal measures draw on the same limited-capacity working memory system.

Several researchers have employed an "n-back" methodology to examine verbal working memory (Awh, et al., 1996; Jonides et al., 1997; Reuter-Lorenz et al., 2000; Smith, Jonides, & Koeppes, 1996; Smith & Jonides, 1999). During this task, participants are presented with a stream of letters that are separated by a brief interval. The task is to determine for each letter whether it matches the one presented "n" items back in the series. For example, in the 2-back version of the task, participants should respond positively if a letter matches the letter that appeared two items previously in the series. If the series of letters were F, B, D, T, C, the next letter would have to be a T to be considered a match; anything else would be a non-match. First, the task involves the storage of one or more letters in working memory. It also necessitates the continuous updating of the contents of working memory—dropping the oldest item, adding the newest, and keeping track of the order of presentation. Thus, the n-back task engages processes involved in storage, rehearsal, and manipulation of information. As expected, increases in processing load make the task more difficult. As the number of trials to be kept in memory increases, response times increase and accuracy decreases. In addition, changes in electrophysiological activation may occur, which the next section will address (Jonides et al., 1997).

The n-back paradigm has the ability to tap both short-term storage and executive processing. As such, it has been utilized to explore the neural substrates of working memory. As a storage task, the paradigm requires the participant to determine if the presented letter matches the letter presented in the first trial. Awh and colleagues (1996) have reported a pattern of left-lateralized activity for such a verbal item recognition task. Using PET technology, they found that storage for verbal information activated left frontal speech regions and the parietal area. Similarly, Smith, Jonides, and Koeppes (1996) reported left-lateralized activation for a mainly verbal storage task, with reliable verbal PET activations in left hemisphere cortical structures – two sites in the posterior parietal cortex and three sites in the prefrontal cortex. From this, they have proposed that while posterior areas of the brain are responsible for storage, more anterior areas become engaged through rehearsal of information. A different picture emerges, however, when executive processes are added to the task, such as occurs when utilizing a 2- or 3-back version of the task. Smith and Jonides (1999) present several studies that demonstrate a pattern of bilateral activation under these conditions, including the study by Smith et al. (1996) showing that the 3-back verbal working memory task elicited activation of not only parietal and anterior areas of the left hemisphere, but also some right hemisphere activation. However, the researchers argue that although there was clear evidence of bilateral activation, there was more activation in the posterior and anterior areas of the left hemisphere than in the right hemisphere.

The preceding section distinguished between simple span tasks, which measure primarily storage for verbal material, and listening/reading spans, which incorporate simultaneous processing and storage of information. The latter type of span better taps into individual differences in verbal working memory. In addition, two levels of n-back tasks were explained. Whereas the easier load version reflects a storage component, the harder load versions (2- and 3-back) engage significantly greater executive processes of working memory. The increase in processing load is accompanied by increases in response time and decreases in accuracy. Neuropsychological evidence supports a view of functional lateralization with verbal storage tasks eliciting greater left-hemisphere activation, but acknowledges that increased processing demands may trigger bilateral activation.

Visuospatial working memory. The second peripheral storage system proposed by Baddeley and Hitch (1974) is the visuospatial sketchpad. A series of experiments by Logie in the late 1980's led to the idea that the visuospatial subsystem is perhaps more complex that Baddeley and Hitch's original model would suggest. He proposed an architect of visuospatial working memory that is divided into subcomponents, in a manner similar to that of the articulatory loop (Logie, 1986, 1989). According to Logie & Marchetti (1991), within the visuospatial working memory subsystem there is a visual part, which allows a person to recognize and categorize an item. This is likened to the “what”, or ventral pathway of Ungerlieder & Mishkin’s (1982) structural model for spatial information processing. Additionally, the spatial portion of the visuospatial subsystem attends to the location, or “where” aspect of the item, and involves the dorsal processing pathway.

Salthouse and Mitchell (1989) differentiated between structural and operational capacities of visuospatial working memory. Whereas structural capacity refers to the span of information units that can be remembered at one time, operational capacity refers to the number of processing and manipulation operations that can be carried out simultaneously, while still preserving the products of earlier operations. A parallel exists between Salthouse and Mitchell’s nomenclature and the distinction between digit and listening/reading spans– both seek to differentiate between passive storage and active processing. Both taxonomies refer to passive storage as structural capacity. Salthouse and Mitchell’s (1989) concept of operational capacity is similar to Daneman and Carpenter’s (1980) functional capacity term because both suggest simultaneous storage and processing, and require the coordinating and attention allocating functions of the central executive.

Law, Morrin, and Pellegrino (1995) were among the first researchers to attempt the design of a visuospatial span task. In their spatial verification task, participants attempted to memorize three to five individually presented 3x3 matrices that had one of nine squares shaded. This aspect incorporated a storage component. To create a demand on active processing, subjects were required to verify an addition equation in which two line matrices were to be added together to create a third line matrix (e.g., Matrix 1 plus Matrix 2 = Matrix 3). This verification task occurred between the presentations of the to-be-stored shaded matrices. Following the presentation of an increasing number of matrix and verification pairs, participants had to indicate on a blank 3x3 matrix which squares had been shaded. Miyake, Friedman, Rettinger, Shah, and Hegarty (2001) strengthened the task properties of Law et al.'s (1995) dot matrix task in several ways in a study that attempted to separate storage-oriented and processing-and-storage tasks in the visuospatial domain. In their version, the participant verifies the matrix equation first, and then views a 5x5 grid with a dot inside it. By doing so, the task more closely mirrors the listening/reading span methodology, by having the processing component precede the storage component. Increasing the memory stimulus from a 3x3 to a 5x5 grid should decrease the likelihood of a verbal memorization strategy during a visuospatial working memory task. Contrary to evidence provided in the verbal domain, Miyake et al. (1995) concluded that visuospatial working memory span tasks and storage-oriented short-term memory tasks equally implicate executive functioning.

The n-back paradigm has also been used to evaluate behavioral and neurocognitive components of visuospatial working memory. The protocol is similar to the verbal working memory tasks, only rather than confirming the matching or non-matching status of the letter's identity, the goal is to compare its location relative to previous trials. In addition, while some researchers have continued to use letter stimuli for the visuospatial tasks (Gevins et al., 2000; McEvoy, Pellouchoud, Smith, & Gevins, 2001; Smith, 1996), other researchers have introduced shapes into the paradigm (Kubat-Silman, 2002; Reuter-Lorenz et al., 2000).

Recall that the Smith, Jonides, and Koeppes (1996) study found left-lateralized activation for verbal storage. The same study reported right-lateralized activation for storage of spatial information. In addition, the more demanding 3-back version of the task elicited bilateral activation, although right hemispheric activation was reliably stronger. Thus, they reported a double dissociation between spatial and verbal working memory tasks. Likewise, Reuter-Lorenz and coworkers (2000) found lateral organization of verbal and spatial working memory for their predominantly storage working memory tasks. They found that female participants (mean age, 23.3) were predominantly left-lateralized for the verbal, and right-lateralized for the visuospatial storage task, particularly in the frontal lobes. More details of this study will be discussed in a later section that compares the working memory of younger and older adults.

Gevins and Smith (2000) utilized a low-load and high-load version of a spatial n-back task to evaluate the effect of processing load on frontal midline theta (fmθ). Power of this signal is typically measured at the anterior midline (Fz) electrode (Gevins et al., 1997), and is usually largest under conditions that require sustained mental effort (Gevins, et al., 1997, 1998). Frontal midline theta appears to be generated by the anterior cingulate cortex, a region that is associated with monitoring conflict within the attentional system (Colcombe, et al. 2000; Posner & Peterson, 1990). The low-load version of the task involved mainly storage of the material, as participants were asked to match the position of the current stimulus (a letter) to the position of the letter in the first block of trials. The high-load version required comparing the current position to the letter's position two screens back. Not surprisingly, a main effect for load was found for both accuracy and reaction time. That is, the increased storage and processing requirements were accompanied by an increase in reaction time and a decrease in accuracy. In addition, fmθ increased as a function of increased storage and processing demand, but only for high, and not low ability individuals (as Wechsler Adult Intelligence Scale-Revised, 1997). It appears that these individuals were better able to maintain sustained attention during the more difficult high-load version of the task.

To summarize, these studies provide evidence that functional lateralization is in place for verbal and visuospatial storage tasks. In addition, tentative support exists for the notion that although tasks involving executive processing trigger bilateral activation, more activation occurs in the left hemisphere for verbal tasks than in the right hemisphere, and vice versa for visuospatial working memory tasks (Smith, Jonides, & Koeppe, 1996). Exploratory and confirmatory factor analyses provide further support for the distinction between verbal and visuospatial working memory. Oberauer and colleagues (2000) grouped twenty-three working memory (WM) tasks along two dimensions. The first was a functional dimension that differentiated tasks by the amount that they reflected storage/transformation, supervision, or coordination of information. The second dimension was the content of the material to be remembered, and included verbal, spatial-figural, and numerical working memory. From their analyses, Oberauer et al. (2000) concluded that whereas storage/manipulation and coordination of information might reflect the same function, supervision was a separate ability. They also found content to be a two-factor dimension, with visuospatial separate from verbal and numerical working memory. Of course, the authors point out that no task taps solely one function and content area – a certain degree of overlap surely exists. It is each individual researcher's responsibility to select the tasks that best represent the qualities of the working memory construct that is central to the theory being tested in any given study.

Likewise, Richardson and Vecchi (2002) conducted a principal components analysis on working memory tasks. They limited their study to six working memory tasks that they have used in their laboratory with some frequency. Their analysis yielded three distinct factors. The first factor was *verbal processing capacity,* as measured by listening span (Daneman & Carpenter, 1980; adapted for Italian samples by DeBeni, Palladino, Pazzaglia, & Cornoldo, 1988) and verbal span (Spinnler & Tognoni, 1987) tasks. The second factor was *passive visuospatial ability*, as measured by visual patterns (Della Sala et al., 1997) and Corsi blocks (Corsi, 1972; Spinnler & Tognoni, 1987) tasks. The final factor was *active visuospatial ability*, as measured by the Jigsaw Puzzle (Vecchi & Richardson, 2000) and mental pathways tasks (Cornoldi, et al., 1991; Vecchi et al., 1995).

These factor analyses lend strong empirical support for the differentiation between verbal and visuospatial working memory, at least from a behavioral point of view. The neuroimaging studies presented (Awh, et al., 1996; Jonides & Smith, 1997; Reuter-Lorenz et al., 2000; Smith et al., 1996; Smith & Jonides, 1999) provide further evidence that different hemispheres and networks of cortical regions are responsible for processing verbal and visuospatial information. However, much of this evidence comes from research conducted on young adults. How does aging affect working memory?

Cognitive Aging and Working Memory

It has been suggested that although age is accompanied by relatively little decline on tasks such as traditional digit or word span tasks, vocabulary, and crystallized intelligence, substantial decrements in performance occur in more complex tasks that involve both the processing and storage of information (Babcock & Salthouse, 1990).

Most studies employing the Daneman and Carpenter (1980) methodology have demonstrated strong evidence for age-related reductions in working memory function. For example, Salthouse and Babcock (1991) used computational and listening span measures of working memory to demonstrate that the distribution of spans systematically shifts toward lower values with increasing age. Their study included 227 adults between the ages of 20 and 87 years of age, who were divided into six groups based on age decades. Group sizes for each decade ranged from 24 to 67 individuals.

The distribution of estimated spans indicates that while approximately 50% of the participants in their 20's had computational spans of 4 to 7 items, over 50% of the participants in both the 60's and 70's decade had computational spans of 2 or fewer items. An even stronger decline was evidenced for listening span. The range of listening spans was 2 to 7 items for the people in their 20's and 30's, with the average span being 4 words. The range of listening spans was 0 to 4 items for decades 50, 60, and 70. Further, the average span was 3, 2, and 1 words, respectively, for these older decades. These shifts in span distributions were reflected in correlations between age and computational span (-.47) and listening span (-.52) estimates.

Another group of researchers have also found a consistently negative relationship between age and listening/reading span. Stine and Wingfield (1987) established a correlation of -.72 between age and working memory span as measured by a version of Daneman and Carpenter's (1980) listening span. Stine, Wingfield, and Myers (1990) replicated these results, finding an age-listening span correlation of -.66. This same study reported a correlation between age and reading span of -.44, while a study by Salthouse (1992) also found a moderate correlation of -.42 between age and reading span.

These age differences in listening/reading span can be contrasted to relatively stable performance on digit and word spans across the age spectrum (Wingfield, Stine, Lahar, & Aberdeen, 1988).

Visuospatial working memory appears to be equally, if not more strongly, vulnerable to age-related changes. Salthouse (1991) has assembled substantial support for the notion that spatial abilities, such as memory for spatial information and spatial manipulation (e.g., segmentation, integration, and transformation) are negatively affected by age.

In respect to spatial information memory, Salthouse (1991) cited over 25 studies that reported significant age differences in the accuracy of recognizing or reproducing geometric designs. Measures of memory for spatial location have likewise demonstrated significantly higher accuracy for younger adults than for older adults (e.g., Cherry & Park, 1989; Park, Cherry, Smith, & Lafranza, 1990). A subset of this type of task has demonstrated that older adults do not perform as well as young adults on a task requiring the reproduction of the position of target cells in a matrix (Salthouse, Kausler, & Saults, 1988). The Benton Visual Retention Test, which taps the ability to reconstruct geometric designs on the basis of a given model, has yielded similar age differences (Robertson-Tchabo & Arenberg, 1989).

Similar to spatial information memory, the ability to manipulate spatial information shows marked decline with age. A wide assortment of tests and procedures has been used to assess this ability. Historically, the range of tasks has included paper folding, surface development, embedded figures, perceptual closure, block assembly, cube comparison, form boards, and the Hooper Visual Organization Test (see Salthouse, 1991, for a review). In the majority of these studies, young adults have consistently performed better than older adults, with negative correlations between age and performance ranging from -.22 to -.69. The ability to segment complex patterns to identify target stimuli is considered a spatial manipulation, and is measured by embedded figure tests. The common finding from such tests is that older adults are slower and/or less accurate than young adults (Panek, Barrett, Sterns, & Alexander, 1978). Tasks that require rotation or folding transformations have also yielded significant age differences (Salthouse, et al., 1990). At least six independent studies have demonstrated older adults having a slower rate of mental rotation, as measured by the classic Shepard & Metzler (1971) task (Berg, et al., 1982; Cerella, et al., 1981; Clarkson-Smith & Halpern, 1983; Gaylord & March, 1975; Jacewicz & Hartley, 1987; Puglisi & Morrell, 1986). In addition, as the angle of rotation is increased, older adults have shown a greater increase in error rates, compared to younger adults (Berg, et al. 1982).

Richardson and Vecchi (1996) utilized a Jigsaw Puzzle imagery task to assess active visuospatial processing in young and older people. In this task, participants are asked to mentally rearrange a scrambled puzzle of a familiar item that has been broken into 4, 6, or 9 pieces. The researchers found significant differences in terms of both correctness and response latency between not only young (mean age = 20.7) and older adults (mean age = 79.3), but also between younger older adults (mean age = 68.9) and older adults (mean age = 79.3). They also found a significant interaction between the effects of age and processing load (number of puzzle pieces), suggesting that as difficulty for the visuospatial task increased, older adults were at an even greater disadvantage.

Several researchers have suggested that visuospatial cognition is even more age-sensitive than verbal cognition. Jenkins, Myerson, Joerding, and Hale (2000) tested young and old participants on verbal and visuospatial processing speed tasks, verbal and visuospatial working memory tasks, and verbal and visuospatial paired-associates learning tasks. All three experiments yielded similar results—although older adults performed more poorly than young adults overall, greater deficits were observed on visuospatial tasks compared to verbal tasks. This was true for both speeded and unspeeded tasks. However, it has also been argued that visuospatial tasks generally hold more novelty than the verbal tasks, and that older adults have greater difficulty processing novel information than younger adults (Kirasic, 1991).

McEvoy et al. (2001) compared the performance and electrophysiological data of young, middle-age, and older male and female participants (all matched for IQ) as they performed two versions of a visuospatial working memory task. The storage task consisted of determining if the presented letter was in the same location as the one presented on the first trial, while the processing task incorporated a 2-back design. They found that average reaction time varied with age, memory load (low or high), and stimulus type (match or non-match). Young adults were significantly faster to respond than both middle-age and older participants. For all subjects, reaction times were longer in the high load than low load condition, and longer for the non-match than match stimuli. These differences also interacted with age. Thus, the increase in reaction time for the higher load was significantly higher for the older group than the younger and middle age group. There was also a greater age-associated increase in reaction time involving stimulus type (match/non–match). In regard to accuracy, there was a main effect for memory load.

McEvoy et al. (2001) also used electrophysiological measures to differentiate the processing of visuospatial working memory among age groups. They limited their analyses to midline channels (Fz, Pz, and Oz). Resting EEG data showed that while older subjects showed significantly greater beta power and young adults had significantly greater delta power, the age differences for theta (θ, 4-7 Hz) and alpha (α, 8-12 Hz) power were not significant. As mentioned in relation to the research of Posner and Peterson (1990), fmθ is enhanced in tasks with greater working memory demands, generated by the anterior cingulate cortex (ACC), and plays an important role in the anterior attentional network. In contrast, increased task demand seems to attenuate α signals (Gundel & Wilson, 1992). It appears that as more cortical neurons are recruited into a transient functional network, the magnitude of α decreases. Thus, α seems to be inversely related to increased effort. The work of Gevins and colleagues (1997, 1998, 2000) supports this hypothesis, as they demonstrated a monotonic attenuation of α in association with progressively demanding working memory load.

McEvoy et al. (2001) found that only younger participants showed an increase in fmθ as task difficulty increased; the middle-age and older groups did not show this attention-related increase. Also, as task difficulty increased the young adults showed a decrease in α power over parietal, but not frontal regions, whereas the middle-age and older groups both showed decreased α power over parietal *and* frontal regions as a function of task difficulty. The authors suggest that these results indicate a difference in strategy, with the younger participants using a strategy that relies on parietal areas, while the older subjects are executing strategies that rely on both frontal and parietal areas. If we consider the writings of Jonides and Smith (1997), this would suggest that the younger adults are relying more on storage processes, while the older adults are depending more on both storage and rehearsal strategies.

Recall the PET study presented earlier by Reuter-Lorenz et al. (2000), in which younger female participants were found to be predominantly left-lateralized for a verbal storage task, and predominantly right-lateralized for the analog visuospatial storage task, particularly in the frontal lobes. In contrast, the authors found a more global pattern of bilateral activation for both verbal and visuospatial memory with their older female participants (average age 69.9). Greater bilateral activation was found in anterior areas, which are associated with rehearsal. Paradoxical laterality was found in the dorsolateral prefrontal cortex (DLPFC), with greater left activation for spatial memory and greater right activation for verbal memory. In relation to performance, the younger group was both faster and more accurate than the older group. These results might suggest that hemispheric specialization, rather than bilateral activation, better supports performance. However, the authors decided to investigate differences within the older group, and divided them according to average reaction time. For the verbal task, the faster older group showed bilateral activation of the DLPFC, while the slower older group showed only right (contralateral) DLPFC activation. Thus, the bilateral activation may be interpreted as beneficial in this situation, as it yielded faster performance. However, such a conclusion is taken with caution, as the split groups became quite small, and the results were not replicated for the visuospatial task.

Functional neuro-imaging studies reveal that aging is associated with expanded, less focused activation patterns during encoding and retrieval stages that may reflect age-related reorganization of system resource management (Grady, et al., 1995). Also, older individuals tend to activate cortical regions that are either not activated or suppressed in younger adults during task performance. It is also possible that older adults must recruit greater nonspecific, or "domain general" resources to tackle an incrementally more difficult task (Kohler, et al, 1998).

Cabeza (2002) proposed a model to explain the pattern of increased bilateral activation seen in some older laboratory study participants. His model, HAROLD (hemispheric asymmetry reduction in older adults), integrates findings about cognition and the aging brain. The HAROLD model states that, under similar circumstances, PFC activity during cognitive performance tends to be less lateralized in older adults than in younger adults. HAROLD is supported by both functional neuroimaging and behavioral evidence in the domains of episodic memory retrieval (Backman et al., 1997; Cabeza, 2002; Cabeza et al., 1997; Grady, Bernstein, Beig, & Siegenthaler, 2002), working memory (Grady et al., 1994; Reuter-Lorenz, 2002), perception (Grady et al., 1994; Grady, McIntosh, Horwitz, & Rapoport, 2000), and inhibitory control (Nielson, Langenecker, & Garavan, 2002).

Two theories have been proposed to account for the functionality of age-related asymmetry reductions. They are the *compensatory view* and the *dedifferentiation view.*

Compensatory view. This view suggests that increased bilaterality in older adults could help counteract age-related neurocognitive deficits (Cabeza, et al., 1997, 2002). Under these circumstances, additional brain regions are recruited in older adults to enable optimal performance. The relation of brain activity and cognitive performance provides support for the compensation hypothesis. The Reuter-Lorenz et al. (2000) study that PET data showed pronounced age differences in areas of activation. Young adults showed a pattern of lateralized frontal activation that was dependent on the type of material held in working memory. Greater left-hemisphere activation was present for verbal materials, and greater right-hemisphere activation was recorded for spatial material. Interestingly, some older adults engaged both right and left frontal regions for both verbal and spatial memory. The authors suggest that this may reflect recruitment to compensate for neural decline. In fact, the older women who displayed a bilateral pattern of prefrontal cortex (PFC) activity performed faster in the verbal working memory task than those who did not. Thus, the bilateral activation may be seen as a successful counteraction against age-related neurocognitive decline.

In addition, bilateral activation may enhance performance as a function of task difficulty. This phenomenon has been demonstrated during episodic memory retrieval. The HERA (hemispheric encoding/retrieval asymmetry) model stipulates that the left PFC is more actively engaged during the encoding of episodic memory and the right PFC shows more activation during retrieval of semantic and episodic memory (Habib, et al., 2003; Tulving, et al., 1994). Although usually a right-lateralized task, left PFC activation has been seen in more demanding retrieval tasks for young participants (Nolde, Johnson, & Raye, 1998). Similarly, Banich (1998) and Passorotti and colleagues (2002) have shown that as task demands increase, performance is optimized when the left *and* right hemispheres are engaged in the task. Reuter-Lorenz and Stanczak (2000) replicated this result, finding the bilateral activation pattern present at lower levels of complexity in older adults compared to younger adults.

The compensation view of HAROLD is also supported by investigations of recovery of function following brain damage. For example, after monohemispheric stroke, the unaffected hemisphere becomes involved in the recovery of both motor function (Netz, Lammers, & Homberg, 1997) and language (Thulborn, Carpenter, & Just, 1999). These findings may serve to challenge long-held beliefs about functional localization, and hint at the potential for lifelong plasticity of the brain.

Dedifferentiation view. The second theory proposed to explain the functionality of age-related decline in lateralization is *dedifferentiation*. This view proposes that aging reverses the trend of early development toward specialization of function (Li & Lindenberger, 1999). The work of Garrett (1946) noted the functional differentiation that occurs during childhood development. He discussed a gradual evolution of distinct cognitive aptitudes rising from an amorphous general ability. Baltes & Lindenberger (1997) hypothesize that this process reverses during aging, and that during dedifferentiation these specific functions return to requiring similar executive and organizing resources. Using simulation studies, Baltes & Lindenberger (1997) found support for the dedifferentiation view, showing that correlations among different cognitive measures and between cognitive and sensory measures tend to increase with age.

A purpose of the present study is to examine how decreases in hemispheric asymmetry relate to performance on various cognitive tasks. If reduction in hemispheric asymmetry (greater bilateral activation) is correlated with better cognitive performance on WM tasks, this finding would support the compensatory view. If, however, increased bilateral activation is associated with poorer WM task performance, this would suggest the presence of dedifferentiation. Whereas the compensation view seeks to explain optimal performance, the dedifferentiation view implies a breakdown in neurological organization. By correlating performance with hemispheric asymmetry patterns, it may be possible to determine which viewpoint, compensatory or dedifferentiation, best explains the bilateral activation normally exhibited in older persons. It will further investigate whether there are differences in hemispheric asymmetry between older active and sedentary individuals. This last point is discussed within the context of the role of physical activity in the preservation of cognitive functioning, and is addressed following the discussion of which processing mechanism best explains age-related changes in working memory.

Theoretical Frameworks to Explain Age Differences in Working Memory

Now that it has been established that age differences exist in both performance and neuropsychological measures of working memory, what theories have been proposed to account for these differences? Two major theoretical orientations will be addressed. First, the role of processing speed in cognitive aging will be addressed. This will be followed by the hypothesis that decrements in attention and inhibitory control contribute to age-related decline in working memory.

Information processing speed and working memory. A popular interpretation of the observed age differences in working memory states that they are attributable to age-related reductions in processing efficiency, reflected by processing speed (Baddeley, 1986; Gick, Craik, & Morris, 1988; Morris, Gick, & Craik, 1988). Salthouse (1991, 1996) suggests that a generalized decrease in the speed at which mental operations can be performed is responsible for the majority of age-related variance observed in a vast realm of cognitive tasks. Processing speed is inferred from perceptual speed tasks, as measured by either simple paper-and-pencil or computerized tests. Regardless of the medium, the participant is asked to make speeded comparisons, or same-different judgments about pairs of digits, letter strings, or symbols. It is a speeded task in that the goal is to make the greatest number of correct comparison responses in a fixed period of time (typically between 1 and 3 minutes).

An impressive amount of evidence provides support for speed of processing as a fundamental process resource underlying cognitive aging (Cerella, 1990; Madden, 2001; Salthouse, 1996). The Digit Symbol Substitution Test (DSST) is hypothesized to reflect perceptual or cognitive speed. The DSST has been a part of the Wechsler Adult Intelligence Scale and its various revisions since 1995, and is relatively easy to administer. The task contains a key showing pairs of digits with hieroglyphic-like symbols at the top of the page. The rest of the page contains rows of boxes with a digit in the top section and an empty space below it. The participant attempts to complete as many boxes as possible within 90 seconds.

Many researchers have demonstrated age differences for performance on the DSST. For example, Salthouse (1988) had 100 young adults and 100 older adults perform a battery of visuospatial tasks, backward digit span task, Digit Symbol Substitution Test, and eight cognitive performance measures. He found that statistical control of the DSST reduced the age differences in the cognitive measure by approximately 63%, while statistically controlling for the backward digit span reduced it by less than 20%. This study provides support for the existence of a powerful perceptual speed component for cognitive tasks. Additionally, a recent meta-analysis has indicated that age-DSST relations are independent of formal years of education, as well as year of task administration (Hoyer, Stawski, Wasylyshyn, & Verhaeghen, 2004). The idea that slower mental processing speed accounts for the majority of cognitive changes associated with aging has been substantiated by a number of other researchers (Cerella, 1985; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Salthouse, 1991, 1996; Salthouse & Babcock, 1991; Salthouse, Toth, Hancock, & Woodard, 1997; Verhaeghen & Salthouse, 1997).

The speed of processing theory is appealing for its parsimony in explaining a multitude of observations. An impressive body of findings shows that the slowing of processing speed (as measured by simple perceptual tasks) accounts for a considerable portion of the age-related variance on a large number of cognitive tasks (Salthouse 1991, 1996). In addition, this amount of variance is generally much greater than that accounted for by other possible mechanisms of age decline in cognitive function. The relationship between measures of speed and fluid processing is attributed to the rate at which to-be-remembered items can be rehearsed or repetitively cycled in the articulatory loop (Baddeley, 1986; Salthouse, 1980), which circles back to the notion of working memory. Thus, the relationship between processing speed and working memory will now be addressed.

Processing speed has been shown to be highly correlated with working memory. In a series of studies, Kyllonen and Cristal (1990) used path analysis to determine a coefficient of .47 between the two constructs. Their processing speed measures included coding tasks and speeded subtests of the Armed Services Vocational Aptitude Battery (ASVAB), while working memory was measured through ABCD (which requires putting sentences in a logical order), digit span, and mental arithmetic tasks.

Similarly, Salthouse and Babcock (1991) performed two studies that found significant correlations ranging from -.39 to -.52 for the relationship between age and working memory. However, these correlations were substantially attenuated by partialing out measures of simple comparison speed. They argue that many of the age differences in working memory might be mediated by age-related reductions in the execution speed of relatively elementary operations. Therefore, they conducted two studies designed to determine which component of working memory is most responsible for age-related decrements in measures of working memory.

In Study 1, the goal was to extricate the relationships among working memory, storage capacity, and processing efficiency. Working memory was measured by conventional computation and listening spans, storage capacity was captured by digit and word spans, and processing efficiency was captured through arithmetic and sentence comprehension tasks. All measures had good split-half reliability, with a median of .89 and a range of .82 to .94. Results indicated systematic shifts with age toward lower computation and listening spans (-.47 and -.52, respectively). A series of hierarchical regression analyses revealed that both storage capacity and processing efficiency played mediating roles in the age-related declines in working memory. Statistical control of storage capacity reduced the age-associated variance to 7%. By controlling for processing efficiency, it was reduced to only 2%. Finally, age-related variance was reduced to only 1% when both storage and processing efficiency were statistically controlled. Thus, efficiency of processing seems to be an important determinant of age differences in working memory. Further, a path analysis indicated that there were no direct paths from age to either storage capacity or working memory; rather, the relationships are indirect and include processing efficiency. However, there were relatively large coefficients for the paths linking age to processing efficiency (-.545) and processing efficiency to working memory (.432).

Salthouse and Babcock (1991) suspected that the processing efficiency tasks from Study 1 may have been too complex. Thus, two relatively simple speeded comparison tasks were employed in Study 2 to capture processing efficiency. These included letter and pattern comparison tasks, which simply required the participant to classify two stimuli as same or different as quickly as possible. Results from Study 1 were replicated, providing even greater support for the speed of processing argument. They found a coefficient of -.515 between age and simple comparison speed, and .711 from simple comparison speed to processing efficiency. In summary, it appeared that all significant age-related influences on working memory, storage capacity, and processing efficiency measures were mediated through the simple speed variable.

Further support for the processing speed theory of cognitive aging comes from the work of Fry and Hale (1996). Their study involved 214 children ranging in age from 7-19 years. Using Ravens Progressive Matrices to measure working memory, they found that over 70% of the effect of age on working memory was mediated through processing speed, with a non-significant path from speed directly to Raven's performance. A study by Ackerman, Beier, and Boyle (2002) involved seven working memory tests, 19 cognitive tests in addition to Raven's matrices, and 16 perceptual speed tests. Their analyses also included the use of path analysis, and they found that eliminating the path between perceptual speed and working memory worsened the fit of their model.

Collectively, these studies underscore the relationship between speed of processing and working memory. Further, the solid evidence regarding the relationship between aging and processing speed suggest that it is not aging, per se, that triggers a decline in working memory capacity. Rather, it is the slowing of processing speed that accompanies aging that is responsible for losses in working memory. Despite the significant amount of existing support for the processing speed theory, rival theories do exist to explain individual differences in working memory. A critical component of working memory is the central executive, which functions, among other things, to allocate attention to necessary subtasks. Therefore, differences in attentional capacity and inhibitory control have been investigated as a means of explaining the aging effects on working memory. The following section addresses this important cognitive construct.

Inhibition and working memory. Attention can be thought of as a processing resource, controlled and coordinated by the central executive. The inhibitory control framework suggests that an inability to ignore irrelevant information affects the storage component of working memory (Hasher & Zacks, 1988).

The inhibitory control view attributes age-related deficits in memory to a decline in attentional inhibitory control over the contents of working memory (Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999). With normal functioning, inhibitory control functions to access goal-relevant information, delete extraneous and no longer needed information, and restrain strong but situation-inappropriate responses. Hasher and Zacks (1988) state that when inhibitory control is deficient, it results in a "mental clutter" of information. It is this momentary increase in clutter that can have subsequent consequences for long-term memory encoding and retrieval. It also affects working memory due to elevated sensitivity to potential sources of interference. More recently, Levitt, Fugelsang, & Crossely (2006) provided results consistent with the notion that attentional capacity mediates aspects of age-related changes in working memory.

If older adults have difficulty suppressing or deleting information from working memory, then memory sets become too large and retrieval is hampered. In essence, attentional mechanisms determine what enters working memory in the first place, and as such influence the output of working memory. Support for this theory comes from experiments in which proactive interference, or carryover, is systematically reduced. Under these conditions, we do not see the age-related differences in memory span between young and old participants (Cerella 1985, 2000; May, Hasher, & Kane, 2000).

Evidence suggests that working memory and attention are substantially intertwined. Engle (2002) states that the central executive allocates attention and regulates the contents of the active portion of memory. He also states that differences in working memory reflect differences in the ability to control attention, and that working memory is only about memory indirectly. Rather, it is more about using attention to maintain or suppress information. Thus, it appears that age-related decrements in attention should negatively affect working memory. Engle, Kane, and Tuholski (1999) argue that working memory tasks reflect a general capacity to maintain task goals in a highly active state. They propose that individuals with higher working memory capacities will be better able to inhibit distracting stimuli and keep attention targeted to a goal state. Conversely, individuals low in working memory capacity will permit distractors to capture attention away from actively maintaining this goal state.

Several studies have supported the idea that interference differences between high and low WM span individuals reflect controlled-attention differences for both a category fluency task (Rosen & Engle, 1997) and a proactive interference task (Kane & Engle, 2000). Kane, Bleckley, Conway, and Engle (2001) continued this line of research by comparing the performance of high and low WM span participants (as determined by operation/word span tasks) on a visual-orienting task known as the antisaccade task (Hallett & Adams, 1980). This is a simple, non-verbal task that requires participants to maintain a task goal in the face of interference. In the prosaccade version of the task, the visual cue predictably signals the spatial location where a target letter will subsequently appear, and the participant must identify the letter. In the antisaccade version, the visual cue appears at a spatial location opposite the location of the target letter. Kane et al. (2001) hypothesized that although performance on the prosaccade task would be equivalent for the high and low WM span groups, individuals with high WM spans would perform better than individuals with low WM spans on the antisaccade task. Their logic was that greater WM span would allow them to maintain goal information in the face of interference. Indeed, the two groups did not differ in how long it took them to identify the target letter in the prosaccade condition. However, low span participants were significantly slower at identifying letters in the antisaccade condition. Similar results in favor of high span individuals were found for goal maintenance during the Stroop task and during dichotic listening tasks. Both of these tasks require the successful inhibition of irrelevant information and controlled attention toward a goal state. Antisaccade tasks have also been utilized to investigate the neural substrates of controlled attention (Sweeney, Mintun, Kwee, Wiseman, Brown, Rosenberg, & Carl, 1996). Their PET study found that antisaccade trials increased dorsolateral prefrontal cortex activation relative to prosaccade trials. In addition, some parietal, temporal, and midbrain areas showed activation.

Support for the inhibitory deficit theory also comes from electrophysiological studies. Dustman (1985) and colleagues (Dustman, Shearer, and Emmerson, 1996; Shearer, Emmerson, & Dustman, 1989) have illustrated that age-related deficits in inhibitory function, as measured with cognitive tasks (e.g., Stroop, Symbol Digit Modalities, and Trails B), can also be associated with weakening of functional boundaries between cortical systems. This analysis was designed after the work of Callaway and Harris (1974), who argued that cortical areas assumed to be functionally linked will demonstrate a high level of similarity in their EEG activity. Thus, cortical coupling is a means of measuring the similarity between pairs of EEG tracings. Dustman et al. (1996) limited their study to Fz, Cz, Pz, and Oz. They grouped the six possible pairs of electrodes into two sets. Set 1 included couplings among the sites of Fz-Cz, Fz-Pz, and Cz-Pz. The second set included Fz, Cz, and Pz each coupled with Oz (Fz-Oz, Cz-Oz, Pz-Oz). They found no age difference in the cortical couplings for the first set of electrode pairings. They did, however, find that EEG couplings for the second set, the ones that included Oz, were larger (more homogenous) for the old than for young men. This would seem to indicate that the cognitive tasks used in this study elicited functional links between the occipital region with the frontal, central, and parietal regions for the older men, but that the young men maintained functional autonomy across cortical systems. From these results, Dustman, Shearer and Emmerson (1996) concluded that decreases in inhibitory function are associated with a weakening of functional boundaries between cortical systems of the older individuals in their study. However, these results might also be interpreted as the older men requiring more sensory-occipital activity than the younger men to perform the task.

Although the inhibitory deficit framework has been supported by other researchers (Girelli et al., 2001; Persad, 2002), it is not without its detractors. Park (1999) states that one of the theory's weaknesses is the inability to develop a reliable individual difference measure of inhibitory function. Schelstraete and Huper (2002) believe that while working memory capacity undoubtedly involves inhibitory control, the vulnerability to intruding responses is not clearly affected by age. They believe that their observed effect of age on reading span must be explained by something other than growing inefficiency of inhibitory control. Likewise, Schilling (2002) utilized the Stroop paradigm and concluded that age makes little contribution to inhibitory function independent of other factors, such as processing speed and intelligence.

Summary of theoretical models. From the above discussion, it is apparent that both the speed of processing and attentional/inhibitory control are viable candidates for explaining how working memory changes with age. Both frameworks are theoretically grounded and possess empirical reinforcement for their assertions. Well-designed studies have shown that each of these theoretical models is capable of explaining the deficits in working memory that are associated with aging. The current study does not intend to provide a definitive answer as to which theoretical model – speed of processing or inhibitory function – best explains the changes in working memory that accompany aging. Rather, it seeks to discover which of these mediators is most influenced by a non-cognitive, lifestyle choice variable—physical activity. The following section will elaborate on the literature related to physical activity and the preservation of cognitive function in general while highlighting the few studies that investigate its relationship to working memory. Finally, the goals and hypotheses of the present study will be proposed.

The Relationship Between Physical Activity and Cognitive Aging

Leading a sedentary lifestyle is a known risk factor for several health conditions including cardiovascular disease, adult onset diabetes, cancer, disability, and depression (Bouchard, 1994). Recently, it has also been implicated in cognitive decline. A growing body of literature suggests that a physically active, rather than sedentary, lifestyle may lead to maintenance of cognitive function (see McAuley, Kramer, & Colcombe, 2004, for a review). The mechanisms behind the physical activity-cognitive maintenance relationship have been elucidated from both animal research and human studies with cross-sectional, longitudinal, and clinical trial intervention designs. More recently, researchers have utilized neuroimaging and scalp recordings of brain activity to better understand the impact of physical activity on offsetting cognitive decline. This area of research holds great promise in aiding our efforts to determine the functional and structural differences in cognition between sedentary and active older individuals.

Several theoretical frameworks appear suitable for explaining the physical activity-cognitive maintenance relationship. For example, it has been hypothesized that aerobic fitness may prevent structural changes in the brain that normally accompany aging. Colcombe et al. (2003, 2006) examined the relationship between aerobic fitness and density of cortical gray and white matter using high resolution MRI. Their adult sample ranged from 55 to 79 years old, and they found evidence that cardiovascular fitness levels significantly moderated the trajectory of age-related tissue loss. There was significantly less gray matter loss in the frontal, temporal, and parietal lobes, and significantly less tissue loss in the anterior and posterior white matter tracts for the older adults with greater levels of aerobic fitness. This proposal has received recent support through the use of magnetic resonance imaging. Colcombe, Erickson, Kirk, and Scalf (2006) found significant increased volume in both gray and white brain matter regions as a result of a six-month aerobic exercise randomized trial. Aerobic fitness may also enhance functioning of neural networks involved in the attentional control exhibited by the frontal lobe (Colcombe, et al., 2004). These findings are of interest, as not only are frontal lobes associated with executive functioning, but also temporal and parietal cortices have been implicated in the storage and rehearsal processes of spatial working memory (Jonides, Lacey, & Nee, 2005).

It has also been suggested that exercise's beneficial effects stem from increased bloodflow to the brain. Early research suggested that brain perfusion and oxygen levels are reduced in elderly people (Frackowiak, Lenzi, Jones, & Heather, 1980). Lowered oxygen levels slow glucose metabolism at the cellular level, and decrease the turnover of neurotransmitters associated with cognitive and motor activities (Gibson & Peterson, 1982; Simon, Scatton, & Le Moal, 1980). Thus, increased cerebral bloodflow as a result of exercise may be a possible mechanism for the maintenance of cognitive functioning. Early research in this area suggested that increases in cerebral blood flow benefit cognitive functioning due to an increased supply of necessary nutrients to the brain, such as glucose and oxygen (Chozko-Zajko, 1991; Madden, Blumenthal, Allen, & Emery, 1989). Along these lines, Dustman and colleagues (1984) hypothesized that maintenance of cognitive functioning in elderly exercisers might result from better transport and utilization of oxygen in the brain and other body tissues. Indeed, the work of Rogers, Meyer, and Mortel (1990) suggests that physical activity moderates the reductions in regional (frontal) cerebral bloodflow that is normally associated with healthy aging. More recent research suggests that changes in cerebral bloodflow due to exercise are transient in nature (Querido & Sheel, 2007), and thus cannot account for long-lasting changes in brain health.

It now appears too simplistic a view to attribute the maintenance of cognitive functioning solely to fitness-related increases in blood flow. If this were the case, we should see blood flow increases in all brain areas related to a given task. Colcombe and colleagues (2004) conducted a two-part study that indicated that this is not the case. In study 1, the researchers collected fMRI scans while participants performed an Ericksen (1999) flanker task, a task similar to the saccade tasks mentioned earlier (Kane et al., 2001). This is a computerized reaction time task that requires responding to a central arrow cue that is embedded in an array of arrows pointed in either the same (congruent) or opposite (incongruent) directions. This task requires the ability to inhibit the incongruent flanking arrows. The ability to do so requires selective spatial attention through frontal and parietal circuitry. These regions function to bias the visual cortex to isolate the central target cue and inhibit the peripheral flanking cues. This inhibition further reduces conflict at the response stage, and should therefore reduce reaction time to an incongruent trial. Because the anterior cingulate cortex (ACC) functions to monitor conflict in the attentional system, Colcombe et al. (2004) hypothesized that successful inhibition should also decrease ACC activation.

Results showed that high cardiovascular fit persons, compared to sedentary persons, showed greater task-related activity in regions of the prefontal and parietal cortices and a decrease in activity in the ACC, demonstrating successful attention to targets and inhibition of distractors. Reaction times also suggested that cardiovascular fitness is related to decreased interference. Had a global increase of blood flow been responsible for their faster reaction times, increases in blood flow would have been observed in *all* task-related regions. Thus, the authors attribute the differences in performance and fMRI to changes in neural recruitment as a function of high cardiovascular fitness.

Study 2 was a randomized clinical trial in which older individuals were assigned to either an aerobic training or stretching and toning control group. After 6 months, participants in the aerobic group, compared to the control group, showed significantly greater task-related activity in the cortical regions associated with attentional control and reduced activity in the ACC. Again, reaction time to incongruent trials was faster for the fitness-trained group.

As compelling as these results are, the inclusion of several important factors would have strengthened their findings. Study 1 did not report the sex of the participants, and neither study compared the older fit group with a younger control group. These methodological omissions leave a gap in our understanding of whether an aerobically fit older brain functions in a manner comparable to a younger adult brain, and if the same effect can be anticipated across sex.

A study by Dustman et al. (1985) was presented earlier demonstrating that increased age is associated with greater uniformity of EEG activity across the brain. They found that the magnitude of EEG power was significantly less variable across midline recording sites (Fz, Cz, Pz, and Oz) for the older participants during cognitive tasks. Dustman and colleagues (1990) followed this study by comparing not only different age groups of men, but also fitness level (as assessed by a maximal exercise test), and included a battery of cognitive tests (Sternberg reaction time, Stroop Color Interference, Symbol Digit Modalities, and Trails B). They again replicated the results of greater homogeneity of EEG across Fz-Oz, Cz-Oz, and Pz-Oz recording sites for the older men. However, older low-fit men had significantly greater mean couplings at these site-pairs than older high-fit men. In addition, the high-fit older men had shorter P300 latencies for a target counting task, better neurocognitive performance, and better visual sensitivity than the low-fit older men. A visual evoked potential (VEP) amplitude/intensity (A/I) slope was also calculated. According to Dustman et al. (1990), a positive A/I slope indicates weakened central inhibition to stimuli. Whereas a positive A/I slope was observed for the low fitness older individuals, this was not present for the higher fit older individuals. Thus, they concluded that aerobic fitness may postpone the decrease in central inhibition that is thought to accompany age. Unfortunately, the authors did not supply the scores of the individual cognitive tests, precluding comparison of verbal vs. visuospatial tasks, and their design was limited to midline EEG sites.

Theoretical Explanations of the Physical Activity/Cognitive Maintenance Relationship

A leading account of the physical activity/cognitive maintenance relationship is proposed by Chozko-Zajko (1991). This line of research is based on the work by Hasher & Zacks (1979, 1988), who proposed that cognitive processes be viewed as distributed along an automatic-to-effortful processing continuum. Whereas automatic cognitive processes are thought to be minimally dependent upon attentional demands, more effortful cognitive processes require a considerable amount of attentional capacity. Thus, Chozko-Zajko (1991) hypothesized that tasks on the more automatic end of the continuum will not show significant benefits from physical fitness. On the other hand, tasks that require more effortful processing, and thus considerable attentional capacity, generally show more age-related decline; Chozko-Zajko (1991) suggests that performance on these tasks will show greater benefits from physical activity.

Several studies have supported Chozko-Zajko's (1991) view that the relationship between physical fitness and cognitive decline is task dependent and a function of the attentional processing demands of the task. First, Spirduso (1980) found greater fitness effects for choice reaction time (CRT) when compared with simple reaction time (SRT). These results have been replicated by Offenbach et al. (1990), who suggested that the additional processing required for the CRT trials augmented the fitness effects. Second, the work of van Boxtel, Paas, Houx, Adam, Teeken, and Jolles (1997) provides additional support for the theory that aerobic fitness may selectively and age-dependently act on cognitive processes, in particular, those that require large attentional demands. They too found an interactional effect with age and task characteristics, with Stroop color/word interference and concept shifting tasks showing a fitness effect but other less effortful cognitive tasks, such as word fluency, failing to do so.

Third, Chozko-Zajko et al (1990) systematically tested high and low fit individuals on a variety of tasks that were distributed along the automatic to effortful continuum. They clearly found the physical activity and cognitive aging relationship to be task dependent, with greater fitness effects for the effortful encoding memory tasks. Thus, Chozko-Zajko (1991) suggests that perhaps physically fit individuals undergo less rapid declines in attentional capacity than their less fit peers, and this enables them to perform better on tasks for which attentional resources are a limiting factor.

Kramer, Hahn, and McAuley (1999) have offered the term "selective influence" to explain their executive control/fitness hypothesis. By this, they imply that enhanced fitness will have the greatest benefit on tasks that involve executive control processes, such as planning, scheduling, task coordination, inhibition, and working memory. Additionally, enhanced fitness will not likely benefit other cognitive processes that do not rely as heavily on executive control.

Support for this selective influence hypothesis comes from the Kramer et al. (1999) intervention study cited earlier. In this study, individuals assigned to the walking group outperformed the control group on three executive control tasks: 1) task switching, 2) response compatibility, and 3) stopping. According to Kramer, these tasks are all dependent on the integrity of the prefrontal and frontal cortices.

Although they use different terminology, these two theoretical frameworks – Chozko-Zajko's attentional model and Kramer et al.'s executive control hypothesis – both stress that the beneficial effects of higher physical fitness in the senior years will be stronger for cognitive tasks that involve greater demand on the central executive of Baddeley's working memory schema. The following sections will review the behavioral literature that supports this idea, whether directly or indirectly. This will be followed by a summary of the animal literature, which strongly implicates physical activity as a mediator of neural plasticity in the aging brain.

Overview of Literature for Physical Activity/Cognitive Maintenance Hypothesis

The exploration of a relationship between physical activity and cognitive function dates back to the seminal work by Spirduso (1975, 1978; Spirduso & Clifford, 1980), who demonstrated that older racquet sportsmen were significantly faster on choice reaction time, but showed no advantage on simple reaction time than their non-exercising counterparts. Clearly, this observation can be explained by the greater attentional demands necessary to execute a decision rather than a simple response to the presence of a stimulus.

Following these early studies, many other researchers have utilized reaction time in an effort to tease apart the relationship between physical activity and cognitive function. In fact, Etnier, Salazar, Landers, Petruzzello, Han, and Nowell (1997) reported that of the 200 studies included in their meta-analysis, 116 included measures of reaction time. “Memory” tasks were also used in 116 studies. Unfortunately, the meta-analysis did not classify memory tasks further, such as short-term, long-term, episodic, or working memory. However, a thorough review of the literature suggests that the construct working memory was not often selected to investigate the effects of physical fitness. Other popular cognitive tests included in the meta-analysis were perceptual (57 studies) and math (40 studies). Only 22 studies included verbal tasks, and surprisingly, only two studies included reasoning tasks.

Clarkson-Smith and Hartley (1989) were one of the few researchers to specifically address the relationship between working memory and physical activity. They selected the 62 most active and 62 least active participants from a larger sample of 300 men and women between the ages of 55 and 91. They found that the performance of older vigorous exercisers on measures of reaction time, working memory, and reasoning were significantly better than their sedentary counterparts. A later study on all 300 individuals from the study (Clarkson-Smith & Hartley, 1990) used structural equation modeling to better understand the relationship between physical exercise and the same three measures of cognitive functioning. They also included age, health, education, and morale in the model. The best-fitting model showed age and exercise affecting each performance variable directly, and a large decrease in the model fit was observed when the path to each performance variable was deleted. However, the working memory measures used in this particular study were all verbal tasks - letter sets, digit span, and reading span, and they did not include visuospatial tasks in their battery of cognitive tasks.

An experiment by Shay and Roth (1992) looked specifically at the association between aerobic fitness and visuospatial performance in healthy older adults. They found conclusive evidence that healthy older men with higher levels of fitness performed better at visuospatial tasks than healthy older men with lower levels of fitness. This fitness effect was not found for either the young or middle-aged groups of men. In addition, no relationships were found between physical fitness and the other cognitive tests administered in the study: verbal memory, attention and concentration, and simple sensory-motor functions.

The three visuospatial tests categorized by Shay & Roth (1992) were the Wechsler Memory Scale Visual Reproduction Test, Rey-Osterrich Figure Test, and the WAIS-R Digit Symbol Test. The authors emphasize that their visuospatial tasks require accurate perception and reproduction of visual information with varying demands placed on the visual memory systems. However, it certainly can be argued that the Digit Symbol Test more accurately assesses information processing speed than visuospatial working memory, and that the visual reproduction and figure tests constitute passive, rather than active, tasks of visuospatial ability. Although they require visual storage, there is minimal concurrent processing involved. According to Richardson & Vecchi (2002), age differences in active visuospatial WM are even more pronounced than those for passive visuospatial WM. This line of reasoning suggests that active visuospatial working memory tasks may reveal even greater differences in performance between high- and low-fit individuals. Another limitation of the Shay and Roth (1992) study is the exclusion of women.

Although the results from behavioral studies such as these show some support for the physical activity/cognitive maintenance hypothesis, it has been argued that superior cognitive performance achieved by high fitness individuals cannot be attributed solely to fitness per se. That is, other factors that covary with the decision to lead a physically active life may also contribute to cognitive performance. These covariates may include diet, alcohol and smoking abstinence, education, and socioeconomic status. Fortunately, some studies have controlled for these variables, while others have not included them in their manuscripts. Additional support for the physical activity-cognitive maintenance hypothesis must come from longitudinal and intervention studies. Both of these designs will now be addressed.

Longitudinal studies. Anstey and Christensen (2000) report that longitudinal study results are generally consistent with the findings from cross-sectional studies. Albert, Jones, Savage, Berkman, Seeman, Blazer, and Rowe (1995), as part of the McArthur Studies of Successful Aging, followed the physical activity of 1,192 older persons and found that self-reported strenuous daily activity around the house was a predictor of cognitive change over a two-year period. High levels of activity were associated with smaller amounts of cognitive change, as measured by a battery of cognitive tests. However, Whitfield, Seeman, Miles, Albert, Berkman and Blazer (1997) did not find the same results from a subsample of African Americans in the McArthur study.

Several other longitudinal studies have shown support for the idea that regular physical activity delays or offsets cognitive decline (Barnes, 2003; Carmelli, et al., 1997; Stessman, 2002). Recently, Wueve and colleagues (2004) reported the results from the Women Nurses Health Study, which began in 1976. Since that time, over 18,000 retired nurses have completed questionnaires every two years, and participated in phone interviews within the last ten years. The researchers found that higher levels of activity, including walking, were associated with better cognitive performance, as indicated by a global score that included the Telephone Interview for Cognitive States (TICS), East Boston Memory Test, Category Fluency, and Digit Span-Backwards. Due to the non-laboratory setting of this study, no measures of change in visuospatial ability were captured.

A recent prospective cohort study was conducted by Abbott et al. (2004) to examine the relationship between walking and future risk for dementia in older men. As part of the Honolulu-Asia Aging Study, 2257 physically capable men (71-93 years of age) kept track of their daily walking distance from 1991-1993. Neurological assessments that screened for dementia were conducted between 1994 and 1999. The findings indicate that men who walked the least (<.25 miles/day) experienced a 1.8-fold excess risk of developing dementia compared with the men that walked the most (> 2 miles/day). Thus, two very recent studies suggest that promoting active lifestyles in both men and women can help late-life cognitive function. However, neither of these studies described have specifically addressed verbal and visuospatial working memory.

Intervention studies. Colcombe & Kramer (2003) conducted a meta-analysis limited to eighteen intervention studies from the years 1966-2001. Their analysis indicated that for older adults, fitness training offers robust, but selective benefits for cognition, with the largest fitness-induced benefits occurring for executive-control processes. Moderating variables for this meta-analysis included several programmatic and methodological factors, such as the length of fitness training intervention, the duration of training sessions, the type of intervention, and the gender of the participants.

A classic study by Dustman and colleagues (1984) demonstrated that participation in a four-month exercise program induced better cognitive performance in tasks such as Digit Symbol, Stroop interference task, and critical flicker fusion, but not in simple or choice reaction time. This benefit was seen only in the aerobic exercise group and not in either the strength and flexibility or the control groups. Likewise, Kramer et al. (1999) randomly assigned adults between the ages of 60 - 75 to either a walking or a stretch and tone group. Similar to the Dustman et al. (1984) study, greater improvements were found for the group that experienced six months of aerobic activity. The attentional and memory tasks they used were designed to tap into executive control processes that are thought to be supported by the frontal and prefrontal cortices. Other studies have shown positive outcomes in cognitive functioning with randomized exercise trials for patients with chronic obstructive pulmonary function- COPD (Etnier & Berry, 2001; Emery, Schein, Hauck, & MacIntyre, 1998). Etnier and Berry (2001) conducted both short-term (3 month) and long-term (18 month) intervention programs and found improvements in fluid intelligence after both intervention lengths. Emery et al. (1998) found that older COPD patients who participated in 10 weeks of exercise, education, and stress management showed improved verbal fluency, but not improved attention, motor speed, or mental efficiency. These gains were not seen for either the waiting list or education and stress management group. It is entirely plausible that a 10-week intervention is not long enough to sufficiently induce changes in cognitive function.

Not all intervention studies have found that increased levels of aerobic fitness are associated with improvements in cognitive function. Blumenthal and Madden (1988) failed to show that a 12-week fitness program improved reaction time performance on a memory search task. However, the men who participated in this study were in their early 40's, an age significantly younger than what is usually considered for cognitive aging studies. They also found that while reaction time was related to initial fitness level, it was not related to increases in fitness level as a result of the intervention. This suggests that while twelve weeks may not have been long enough to elicit significant changes in cognitive function as a result of exercise, a physically active lifestyle leading up to the intervention may predict performance in this particular task.

There are several other intervention studies that have not shown support for the physical activity-cognitive maintenance hypothesis. Madden and colleagues (1989) found no improvement in reaction time, attention or memory retrieval as a function of aerobic training for a group of 85 older adults. In other studies, aerobic fitness has failed to show improvements in logical memory (Hill, Storandt, & Malley, 1993), fine motor skills (Normand, Kerr, & Metivier, 1987), and reaction time (Panton et al., 1990). Again, it is important to note that these researchers did not use working memory as a dependent variable.

Given the relatively short intervention duration for the studies that failed to support the physical activity/cognition relationship, it seems plausible to suggest that any benefits in cognitive functioning related to fitness might develop over a lifetime of physical activity and not across several weeks or months.

Evidence from animal models. The majority of animal studies have focused on exercise's beneficial effects on brain plasticity. There are only a small number of studies that have investigated the behavioral effects of exercising on aging animals; however, their results are consistent. Fordyce and Farrar (1991) have demonstrated that rodents who have engaged in physical activity show enhanced performance in spatial learning, which is considered a hippocampal-dependent task. Rats who engaged in extensive treadmill running (30 minutes a day, 5 days a week) for a period of six months showed enhanced performance on a place learning task. Their second trial latencies were reduced, and they had greater proximity ratio scores than the non-running controls. The researchers also attributed the improvement in spatial learning to the running-induced increases in the hippocampal cholinergic system, which is believed to show a progressive decline with age. Anderson and colleagues (2000) likewise found that exercising rats not only learn routes better, but learning latency is decreased. These results suggest that exercise induces more efficient brain functioning. Further evidence (Klintsova, et al., 1998) suggests that rodents engaged in motor skills training were able to generalize these skills to novel motor tasks far better than control groups that engaged in either light exercise (forced walking in a closed alley) or inactivity (daily handling). In summary, it appears that engaging in physical activity enhances rodents' ability to efficiently learn novel spatial configurations and to transfer learned skills to novel motor tasks. This suggests an indirect link between physical activity and changes in the rodents' brain functioning. The following section addresses this relationship directly.

It is thought that enhanced brain and cognitive plasticity is the mechanism through which physical activity affects the aging brain (Churchill, et al., 2002). Research with animals has led to the conclusion that brain plasticity continues to occur later in life, and can be triggered by exercise. A significant body of research indicates that exercise affects the brain functioning of rodents through the processes of synaptogenesis and neurogenesis.

Synaptogenesis is the process by which existing neurons expand the number of contacts made with surrounding neurons. Rodent and monkey studies have employed the complex environment paradigm, where the conditioned animals live in large cages that are filled with a variety of objects that encourage exploration and physical activity. These items are replaced or repositioned on a daily basis to maximize learning. Control animals are either housed individually or live in social cages that contain only food, water, and bedding. Several researchers (Juraska, 1984; Volmar & Greenough, 1972) have found evidence for neuronal synaptogenesis in the cerebral cortex and cerebellum of animals placed in the enriched environments.

While it was once thought that new cell growth, or neurogenesis, occurred mainly during the early years of development, the concept of later neurogenesis is gaining general acceptance. It has now become clear that some regions of the adult brain can respond to environmental stimuli by adding new neurons (Churchill, et al., 2002). These areas include the adult rodent hippocampus (Kuhn, Dickinson-Anson, & Gage, 1996) and the olfactory bulb and hippocampus of non-human primates (Gould, et al., 1997; Kornack & Racik, 1999).

Exercise and enriched environments appear to be important stimulants for neurogenesis in the dentate gyrus, which is part of the hippocampus. Wheel running appears to increase the rate of neuron proliferation in the rodent dentate gyrus, compared to both learning and inactive control animals (van Praag, Kempermann, & Gage, 1999). In fact, the voluntary exercise increased cell proliferation and survival to the extent of doubling the number of surviving newborn cells, comparable to increases induced by enriched environments. Additionally, these authors have shown that this increased neurogenesis is related to improved memory function and enhanced synaptic plasticity for the mice. Interestingly, these results were not seen for mice that underwent maze training or yoked swimming (Brown, Cooper-Huhn, Kempermann, van Praag, Winkler, Gage, & Kuhn, 2003). Thus, motor training alone is not sufficiently capable of inducing neurogenesis of hippocampal cells. It appears that, at least for rodents, physical activity increases neurogenesis in the hippocampus to at least levels found with exposure to enriched environments.

Given the growing evidence of hippocampal neurogenesis, an important question to ask is what stimuli can modulate the proliferation and survival rate of these newly formed neurons? Two possible answers are fibroblast growth factor and brain-derived neurotrophic factor.

Gomez-Pinilla and colleagues (1998) have demonstrated that spatial learning and physical activity contribute to the induction of fibroblast growth factor. This is a neural substrate responsible for enhancing long-term potentiation in the hippocampus, among other functions. Using rats and the classic Morris water maze paradigm, Gomez-Pinilla et al. (1998) demonstrated that physical activity and learning serve to regulate this important tropic factor that is linked with cellular plasticity.

Cotman and Berchtold (2002) found that after several days of volunteer wheel running, the levels of brain-derived neurotrophic factor (BDNF) mRNA increased in the mouse hippocampus. The authors suggest that BDNF is a better candidate than fibroblast growth factor for mediating the long-term benefits of exercise on the brain. Russo-Neustadt and coworkers (2001) have also shown that BDNF mRNA is up-regulated in response to exercise and can induce neurogenesis in brain areas that do not commonly undergo neuronal proliferation (Pencea, 2001). Similarly, Shetty and Turner (1998) suggest that not only can experience and exercise influence the survival rate of new neurons, they can also selectively direct proliferating cells to a specific neuronal fate.

Animal models have played an important role in our understanding of how exercise benefits hippocampal dependent tasks in rodents, along with some of the neuronal changes that occur in response to exercise. Research by Barnes, Nadel, and Honig (1980) also suggests that older rats may use different strategies, and thus brain areas, to overcome spatial memory deficits. Studies such as these shed hopeful light in furthering our understanding of how the human brain may retain plasticity of function as a result of physical activity.

Summary

This introduction has reviewed cognitive aging in general, with specific emphasis placed on age-related declines in verbal and visuospatial working memory. It has explored two theoretical frameworks to explain why working memory, which is so critical to higher cognitive processes, seems to suffer as we age. The cognitive aging theories that have been explored in this paper are: information processing speed and attention/inhibitory function.

Evidence supporting the relationship between cognitive aging and physical activity has been presented. Although thirty-plus years of research has provided substantial support for the idea that engaging in regular physical activity may forestall cognitive decline, the vast majority of studies have not emphasized which specific cognitive processes or mechanisms may be responsible for the physical activity/cognitive maintenance relationship. One key candidate may be to explore the relationships among aging, physical activity, and working memory.

Fortunately, a reasonable amount of electrophysiological research has offered a preliminary understanding of how aging affects working memory. Researchers have identified differential patterns of hemispheric reductions in alpha amplitude in both parietal and frontal regions and midline frontal theta as young and older individuals engage in working memory tasks. Thus, the present study sought not only to identify working memory as an important player in the physical activity/cognitive maintenance relationship, but also to find electrophysiological evidence to this end. It also attempted to provide correlations between cognitive performance and EEG patterns, so that theoretical issues, such as compensation and dedifferentiation, could be addressed.

Present Study

Previous research suggests a strong relationship between aging and decline of cognitive function (Birren & Schaie, 2001; Craik & Salthouse, 2000; Park & Schwarz, 2000; Salthouse, 1991, 1996). Another body of research indicates that a regular routine of physical activity may moderate this relationship (Churchill et al., 2002; Colcombe et al., 2004; Etnier et al., 1997). Because working memory, the ability to simultaneously store and process information, is considered critical to higher cognitive functions, it is a relatively commonly used index of cognitive aging. Although several researchers have investigated the relationship between physical fitness and working memory (e.g., Clarkson-Smith & Hartley, 1990; Kramer et al., 1999, Kramer et al., 2003), the term "working memory" has represented an array of tasks that might better be defined as attention, task-switching, or just plain memory tasks. The present study utilized a more narrow definition of working memory that includes not just storage, but continual updating of material in memory, such as the span and n-back tasks used by Smith & Jonides (2000), Reuter-Lorenz et al. (2000). The exception to this is the recent study by Bugg, DeLosh & Clegg (2006), who did use a working memory task that required both storage and updating. Thus, the primary objective of the present study was to determine whether older individuals who engage in regular physical activity demonstrate superior working memory, as defined by span and n-back task performance, relative to older sedentary individuals.

A second objective of the study was to compare fmθ and α among older and younger, sedentary and physically active individuals. Previous studies suggest that as task difficulty in a working memory task increases, younger, but not older individuals show an increase in fmθ (McEvoy et al., 2001). The present study seeks to not only replicate this finding, but to provide additional evidence that while the older sedentary group will demonstrate this lack of increase in fmθ, it will be present for the older, physically active group. McEvoy et al. (2001) reported significant age differences for reaction time and lower accuracy scores for older adults as task difficulty increased; however, this age x memory load interaction failed to reach significance. In the present study, it was hypothesized that the older groups will be significantly less accurate *and* slower than the younger groups as task difficulty increases from storage-only to storage-plus-processing requirements. The present study also strove to illustrate that a positive relationship exists between fmθ and task performance. This relationship, coupled with a finding that physically active older individuals show an increase in fmθ as a function of task difficulty would establish an empirical link between physical activity and better cognitive function.

Past research regarding α is not quite as straightforward as the literature on fmθ, and few studies regarding physical activity have included it. Thus, the present study tried to augment our understanding of *how* physical activity may function to maintain cognitive ability into old age. The n-back working memory tasks proposed in the present study were selected specifically to elicit a pattern of hemispheric lateralization in the young group. For this group, it was hypothesized that asymmetric patterns of α would be present for the storage-only condition. That is, greater right parietal (P4) α would be present for the verbal task, and greater left parietal (P3) α would be present for the visuospatial task. It is important to remember that a reduction in alpha is associated with activation. Thus, a positive asymmetry index (R-L/R+L) represents a reduction in alpha amplitude in the right hemisphere, connoting a more relaxed state and thus inferred greater dependence on the left hemisphere. Conversely, a negative asymmetry index (R-L/R+L) infers the opposite, a greater dependence on the right hemisphere. As the task demands progress from storage-only to storage-plus-updating, it wass expected that the younger group would show further decreases in parietal, but not frontal α. This finding would demonstrate a reliance on memory, rather than executive function to execute the more demanding task. It was also thought possible that reductions in α may no longer show patterns of hemispheric asymmetry based on task (verbal vs. visuospatial) characteristics (Jonides, et al., 1997). In other words, the asymmetry index may approach zero, indicative of approximately equal activation between the hemispheres for both verbal and visuospatial tasks.

Previous research by Reuter-Lorenz and colleagues (2000) suggests that older individuals exhibit a lack of hemispheric specialization even for simple tasks. Their study utilized PET technology, and the present study attempted to replicate these findings using EEG. Thus, bilateral reduction in alpha was hypothesized to be present during the storage-only condition for the older group, and that older individuals were predicted to display further decreases in α over both frontal and parietal areas (F3, F4, P3, P4) as task load increased. Such a finding would suggest a reliance on both memory and executive processes to complete the task. It would also lend support to Cabeza's (2004) HAROLD model; however, as is, this finding would not aid in our understanding of whether the phenomenon represents compensation or dedifferentiation. In order to investigate this question, performance needed to be considered along with asymmetry indices. If it were found that a decrease in asymmetry, or conversely, an increase in bilateral activation is associated with better task performance in the older group, then this would support the compensatory view. If however, bilateral activation is correlated with poor task performance, this would seem to indicate that dedifferentiation is the causal factor. What if no relationship is found between bilateral activation and performance? What interpretation can be made in this circumstance? Perhaps the inclusion of physical activity as a moderator variable will prove helpful. What can be inferred should the older physically active group show a positive relationship, and the older sedentary group show a negative relationship, between bilateral activation and task performance? This would seem to suggest compensation for the former group, and dedifferentiation for the latter group, and that physical activity may be the key to successful compensation. Indeed, this stance is certainly supported by the animal literature (Cotman & Berchtold, 2002; van Praag, Kempermann, & Gage, 1999).

The third major objective was to evaluate the degree to which physical activity underscored the roles that speed of processing and inhibitory function play in the maintenance of working memory during the aging process. Both constructs have been linked with working memory. Researchers such as Salthouse and Babcock (1991), and Ackerman, Beier, and Boyle (2002) would argue that processing speed, as measured by perceptual tests, is responsible for age-related losses in working memory. However, other researchers (Engle, 2000; Hasher & Zacks, 1988) believe that age-related decrements in attention and the inability to disinhibit irrelevant information (as measured by saccade tasks), negatively affect working memory. Therefore, the present study evaluated the extent to which both of these theories contribute to working memory, in relation to aging and physical activity.

Design

Separate between-subjects designs were utilized to investigate speed of processing, inhibitory function, and verbal and visuospatial working memory spans as a function of age and physical activity. Two levels of age represented young and older participants, and participants were categorized into two levels of physical fitness (sedentary or physically active). Speed of processing was measured by the Digit Symbol Substitution Task (WAIS-III, 1997), and attention/inhibitory function was measured by a saccade/antisaccade task (after Kane, Bleckley, Conway, & Engle, 2001). Verbal working memory span was measured by a reading span task (after Daneman & Carpenter, 1980; Kane et al., 2001), and visuospatial span was measured with a dot matrix span task (after Miyake et al., 2001).

Two mixed designs were used to investigate verbal and visuospatial working memory (as measured by n-back tasks) performance. Age and physical activity were between-subjects factors. Two levels of task load were manipulated within participants for both verbal and visuospatial N-back tasks (after Gevins & Smith, 2000): an easy condition (storage only, zero-back) and a hard condition (storage and updating, 2-back). Dependent measures included accuracy and respone time.

Two mixed designs were employed to investigate α and fmθ. Age and physical activity were between-subjects factors and task load and site were within-subjects factors. Electrodes placed at Fz, F3, F4, P3, and P4 recorded α (8-12 Hz). An electrode placed at Fz recorded fmθ (5-7 Hz).

A mixed design was employed to investigate α and fmθ. Age was a between-subjects factors and physical activity, task type, task load, and site were within-subjects factors. Electrodes placed at Fz, F3, F4, P3, and P4 recorded α (8-12 Hz). An electrode placed at Fz recorded fmθ (5-7 Hz).

Hypotheses

1) Based on previous findings (Cherry & Park, 1989; McEvoy et al., 2001; Salthouse & Babcock, 1991), it was predicted that the young group would have larger verbal and visuospatial working memory spans than the older group. It was not anticipated that the two groups would show any significant differences in performing the verification portion of the tasks; however, the very act of processing would interfere with the older groups' memory portion of the tasks. Consistent with the cognitive aging literature, a main effect for age was expected for both processing speed and inhibitory function.

2) Because working memory *may* be the mechanism by which physical activity maintains cognitive function during aging, it was hypothesized that there would be an age x physical activity interaction for both verbal and visuospatial working memory tasks. That is, the physically active older group would have larger verbal and visuospatial working memory spans than the sedentary older group.

3) Based on the research of Reuter-Lorenz and colleagues (2000), it was hypothesized that while both younger and older groups would show an equal ability for the easy, storage-only condition of the verbal and visuospatial n-back tasks, the younger group would perform these tasks significantly faster than the older group. In addition, a main effect for task load was expected, in that all participants were expected to have decreased accuracy and longer reaction time as the task load changes from easy to hard (storage only to storage plus updating). However, an interaction effect was expected, in that this task-load induced decrement in performance would be greater for the older group compared to the

younger group. Finally, should regular physical activity help preserve working memory, it was hypothesized that then there would be a three-way interaction among age, physical activity, and task load, with the physically active older individuals having better accuracy and faster reaction time than the sedentary older individuals as a function of task load difficulty.

5) As discussed earlier, the work of McEvoy et al. (2001) suggests that fmθ increases as a function of task load. As the task becomes more demanding, fmθ, as measured at Fz, increases. Thus, it was predicted that there would be a main effect for task load on fmθ in the present study. It was further hypothesized that there would be an interaction between age and taskload, wherein the younger group would show a greater increase in fmθ than the older group as a function of increased task demand. Finally, if the ability to successfully utilize attentional processes (inferred to be the ACC, as measured by fmθ) is a byproduct of physical activity in the elderly, then a three-way interaction among age, physical activity, and taskload on fmθ was be predicted.

6) From the literature, it can be concluded that α is affected by several variables working in combination. Thus, it was not anticipated that a main effect for age on α would be observed. However, several three-way interactions were predicted. In further support of the results reported by McEvoy et al. (2001), it was hypothesized that while the younger group would show asymmetrical activation for task type (with the verbal n-back easy task eliciting a positive asymmetry index and visuospatial n-back task exhibiting a negative asymmetry index), the older group would show a more global pattern of bilateral activation (as evidenced by an

asymmetry index approaching zero). It was hypothesized that as taskload increased, both young and older groups would show a bilateral pattern of α activation. It was further hypothesized that whereas bilateral activation will be positively correlated with working memory performance for the physically active group, it will be negatively correlated with the sedentary older group.

METHOD AND PROCEDURE

Participants

Forty (20 physically active and 20 sedentary) young adults between the ages of 18-30 years old and forty (20 physically active and 20 sedentary) older adults age 60 and above were selected for the study. The average age for the young adults was 20.8 years (SD = 3.20) and the average age for the older adults was 67.3 years (SD = 4.50). All participants were right-handed, and attempts were made to recruit a comparable number of males and females in each group. Participants were recruited from the University psychology research pool, University e-mail announcements, local newspaper advertisements, and flyers posted at local senior centers, YMCA, the local running club, and the local running and cycling stores. All of the participants were prescreened via a brief telephone interview for physical activity level, handedness, and medical history to determine inclusion in the study. Potential participants were categorized as either sedentary or physically active based on their responses to the Carpenter Physical Activity Questionnaire (Appendix A, after Paffenbarger, Wing, & Hyde, 1978). Participants received either four psychology department research participation credits or $20 for their participation.

Participants' demographic, computer background/experience, health/lifestyle behavior, depression, mental state, and vocabulary scores were analyzed and the results are reported in the following section.

Participant Background Information

A chi-square test of homogeneity revealed that the four groups (younger sedentary, younger active, older sedentary, and older active) were not significantly different for the demographic variables of sex, ethnicity, driver's license, socially active, computer experience, and smoking status (see Tables 1 and 2).

Table 1
Gender and Ethnicity Demographics of Participants

	Younger		Older			
	Sedentary (n =20)	Active (n =20)	Sedentary (n =20)	Active (n =20)		
Variable	n	n	n	n	χ^2	p
Gender					3.81	.283
Male	7	9	9	13		
Female	13	11	11	7		
Ethnicity					13.24	.352
Caucasian	13	18	17	19		
African American	4	1	3	1		
Hispanic/Latino	1	1				
Asian	1					
Other	1					

$* p < .05$, $** p < .01$

Significant age group differences did exist for education, occupational status, computer usage, average alcohol consumption, and overall health self-rating. The older groups completed more education than the younger groups, χ^2 (9, N = 80) = 29.47, p = .001. Whereas 100% of the younger groups were current students, the older sedentary group was 70% retired, 30% other (part-time employment) and the older active group was 75% retired, 25% other, χ^2 (6, N = 80) = 80.25, $p < .001$. Both younger groups were far more likely to use computers on a daily basis compared to the older groups, χ^2 (12, N = 80) = 29.93, p = .003. Lifestyle variables indicated that the older active group had a higher alcohol consumption than the other three groups, χ^2 (9, N = 80) = 19.92, p = .018. Finally, the older active group rated their overall health as higher than the other three groups, χ^2 (6, N = 80) = 13.21, p = .040.

Table 2

Demographic Characteristics of Participants

	Younger		Older			
	Sedentary (*n* =20)	Active (*n* =20)	Sedentary (*n* = 20)	Active (*n* = 20)		
Variable	*n*	*n*	*n*	*n*	χ^2	*p*
Education					29.47	.001**
Completed HS			4	2		
Some College	18	17	8	3		
College Degree		2	5	5		
Advanced Degree	2	1	3	10		
Occupational Status					80.25	.000**
Student	20	20				
Retired			14	15		
Other			6	5		
Valid Driver's License	20	20	20	20		
Socially Active					1.14	.768
Somewhat	6	5	8	7		
Very Much So	14	15	12	13		
Computer Usage					29.93	.003**
Never			3	1		
< once a month			1			
Once a week			5	1		
Every 2-3 days	1		3	3		
Every day	19	20	8	15		
Computer Experience					16.87	.155
Don't use computers			3	1		
< 1 year		1				
2-5 years	2	1	5	1		
5-10 years	10	10	6	7		
> 10 years	8	8	6	11		
Average Alcohol Consumption					19.92	.018*
None	13	5	12	5		
Up to 1 drink/week	4	10	5	8		
2-6 drinks a week	3	5	2	3		
≥1 drinks a day			1	4		
Smoking					8.35	.214
Never	16	16	12	10		
Past	3	3	8	9		
Current	1	1		1		
Overall Health Self-Rating					13.21	.040*
Good	7	3	7	1		
Very Good	11	12	7	9		
Excellent	2	5	6	10		

* $p < .05$, ** $p < .01$

Apparatus

Computer Monitor. All visual stimuli were presented on a computer monitor positioned 60 cm from the seated participant. All visual stimuli were presented at a minimum font size of 18. Responses were be made on a standard keyboard.

EEG. EEG was recorded from 10 mm pure tin electrodes placed according to the International 10/20 system (Jasper, 1958, see Appendix B). Recordings were gathered from midline frontal (Fz), left and right frontal (F3, F4), and left and right parietal (P3, P4) locations, referred to both Cz and computer-derived averaged-ears references using Cz- left ear (A_1) and Cz- right ear (A_2) channels. The right mastoid served as the ground, and Fp1 recordings were used to edit and remove electro-oculographic activity.

Screening Instruments

Carpenter Physical Activity Questionnaire. This instrument required participants to assess their leisure time physical activities (e.g., exercise, sports, recreation, and hobbies) as part of, as well as beyond, their regular employment duties, as well as using physical activity as a means of transportation (e.g., riding a bicycle to work). It asked how many days per week, if any, were spent engaging in physical activity, and to classify any physical activity as either moderate or vigorous intensity. Participants were classified as sedentary if they responded that they do not engage in physical activity as part of their regular job or household duties, and responded “never” or 1-2/week for using physical activity as a means of transportation. Participants were classified as physically active if they met either of the following criteria: (a) engaged in moderate-intensity physical activity (at least 30 minutes per session) for 5 or more days a week, or (b) engaged in vigorous-intensity (at least 20 minutes per session) for 3 or more days a week.

This classification was based on the United States Surgeon General's Report on Physical Activity and Health (1996). Twelve potential participants indicated during the telephone interview that they did not meet either criteria and thus were excluded from further participation in the study.

Demographic/medical history questionnaire (See Appendix C). This instrument collected information on age, education, sex, ethnicity, occupation, medical history, and medication (prescription and over the counter). No participants were excluded from participation based on the medication they were taking.

Handedness questionnaire. (Chapman & Chapman, 1987; See Appendix D). Due to the emphasis of lateralized cerebral functioning in the current study, this questionnaire was used to determine if potential participants can be categorized as right-handed. It is a 13-item questionnaire found to have high internal consistency for both males and females (coefficient $\alpha = .96$ for both sexes), high test-retest reliability ($r = .97$ for males, $r = .96$ for females, and a correlation of .83 with a 10-item behavioral measure of handedness. Participants indicate whether they ordinarily use their right (1) left (2), or either hand (3) for a list of activities. Scores of 13 to 17 indicated right-handedness and inclusion in the study. Four participants were excluded from the study based on their handedness responses during the phone interview.

Visual acuity. Visual acuity was screened using a Snellen handheld near vision chart. All participants met the minimum criteria of 20/40 corrected vision to participate in the study.

Vocabulary test (WAIS-III, 1997; see Appendix E). This test was administered to determine if differences in verbal comprehension, or crystallized knowledge, exist between the young and older groups. It contains a series of 33 orally and visually presented words that the participant is asked to define orally. Answers were scored as 2, 1, or 0 points. The task ends when the participant has six consecutive scores of 0. The reliability coefficients for 18-30 year old age groups range from .92 to .94, and from .93 to .95 for the 60-89 year old age groups.

Mini mental state exam (MMSE - Folstein, Folstein, & McHugh, 1975*;* see Appendix F). The MMSE is a tool used for assessing mental status and identifying possible cognitive impairment. The 11 items test five areas of cognitive function: orientation, registration, attention and calculation, recall, and language. The maximum score is 30, with a score of 23 or lower indicative of cognitive impairment. Because no participants scored less than 26, none were excluded from the study.

Geriatric depression scale (GDS; Sheikh & Yesavage, 1986*)* (See Appendix G). This 15-item instrument screens for depression, which may be associated with cognitive decline in elderly populations. It has several advantages over other commonly used depression scales, such as the Beck Depression Inventory (Beck, 1961). The GDS was developed and tailored specifically for use with the elderly, avoiding questions that relate to current employment and those that may raise the defensiveness of participants or otherwise reduce cooperation (e.g., questions about sexuality). It also avoids an emphasis on somatic complaints (e.g., questions such as those regarding disturbed sleep patterns, as older adults may suffer from physical conditions or medication that disturb sleep). Scores >5 indicate probable depression, and no participants were excluded from the study based on this depression scale.

Cognitive Tasks

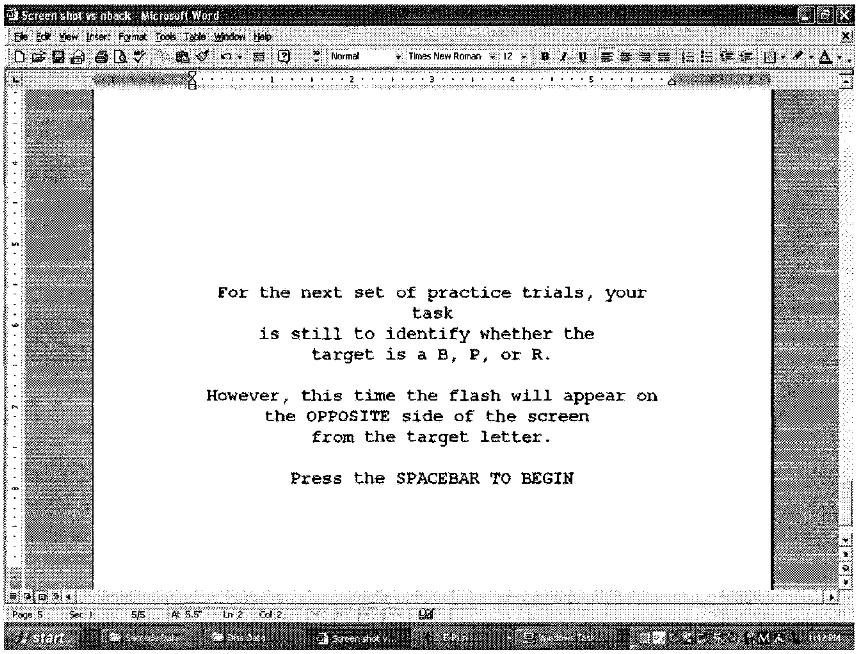
Each participant completed the following six cognitive tasks: (1) Digit-Symbol Substitution Task, (2) Reading Span, (3) Dot Matrix Span, (4) Saccade Task, (5) Verbal n-back, and (6) Visuospatial n-back. The presentation order was constant for the first four tasks. The verbal and visuospatial n-back tasks were presented in a counterbalanced order.

*Digit symbol – coding/digit symbol copy (*WAIS-III, 1997*).* This task is designed to measure information processing speed. Test-retest reliability coefficients range from .90 to .92 for the 18-30 year old age group and from .93 to .84 for the 60-89 year old age group. The Digit Symbol Task is divided into two segments – Coding and Copy (See Appendix H). For the Digit Symbol-Coding component, the participant was presented with a series of numbers, each of which is paired with its own corresponding hieroglyphic symbol. Using a key, the participant wrote the symbol that corresponded to its number. After a practice period, the participant was instructed to complete as many items as possible within a 120-second time limit. For the Digit Symbol-Copy component, the participant was instructed to simply copy the symbols that were used in Digit Symbol-Coding. Each symbol appears in a box with a blank below it where the participant will copy the symbol. The participant is instructed to complete as many items as possible within the 90-second time limit. This component is a measure of perceptual and graphomotor speed, and needs to be separated from information processing speed. A Processing Speed Index was calculated by subtracting the Copying Rate from the Coding Rate (after Tun, Wingfield, & Lindfield, 1997).

Saccade task. This task was modeled after the task used by Kane, Bleckley, Conway, and Engle (2001). It was designed to measure the ability to disinhibit distracting material. The basic requirement was to identify the target stimulus (the capitalized letter B, P, or R, presented in 20-point font) as quickly and accurately as possible. The 1, 2, and 3 keys on the number pad of the keyboard were labeled with colored stickers B, P, and R, respectively. The target letters B, P, and R occurred an equal number of times in each practice and experimental block. The index, middle, and ring fingers of the right hand were resting on these keys throughout the task. The task consisted of three types of task blocks: "response mapping blocks", a prosaccade experimental block, and an antisaccade experimental block.

The response mapping practice blocks had 18 trials within each block. The purpose of these practice blocks was to familiarize participants with the location of the response keys. There were six trials for each practice letter, presented in a randomized order, where the letter appeared in the center of the computer screen. Each block began with a "READY?" prompt that remained on the screen until the participant pressed the space bar. This was followed by a 400-ms blank screen. Following this, a fixation signal (***) appeared at the center of the screen for 200 ms. A 100-ms blank screen followed the fixation screen, and then the target letter appeared in the center of the screen for 100 ms. The target was followed by a backward masking stimuli – an *H* for 50 ms, and then an *8* for 50 ms, followed by a blank screen for 2000 ms, during which time the participant made a response. Accuracy and reaction time data were presented on the screen immediately following the response. All participants met the 85% criteria after four practice blocks. The participant then engaged in the 18-trial experimental block.

The prosaccade practice block was similar to the response mapping practice blocks, except that the target letter appeared to the right or the left of the fixation, and the target location was cued by a flashing "=" symbol. Immediately after the *** symbol disappeared, a 50 ms blank screen appeared and was followed by the "=" for 100 ms, located either to the right or left of the fixation. Another blank screen of 50 ms followed, as well as another 100 ms for the second "=". Thus, the "=" appeared to be flashing, and a strong attractor of attention. Following another 50 ms blank screen, the target letter appeared in the location that had been occupied by the cue. Target duration and masking sequence were the same as those in the response mapping practice. All participants met the 85% criteria after four practice blocks. After the prosaccade practice block, the experimental block of 72 trials began. Every combination of the three targets, six fixation durations, and two stimulus locations occurred twice across the 72 trials.



For the next set of practice trials, your
task
is still to identify whether the
target is a B, P, or R.

However, this time the flash will appear on
the OPPOSITE side of the screen
from the target letter.

Press the SPACEBAR TO BEGIN

Figure 1 . Participant Instructions for Antisaccade Task.

The antisaccade practice and experimental blocks were identical to the prosaccade blocks with one important exception. In these blocks, the "=" cue always appeared on the opposite side of the screen from the upcoming target stimulus (see Figure 1). Thus, if the cue appeared on the left of the screen, the target appeared on the right side of the screen, and vice versa.

Working Memory Tasks

N-back tasks. These tasks were designed to examine an individual's ability to simultaneously process current stimuli and compare it to the sequence of stimuli held in memory. They were modeled after the methodology used by Gevins & Smith (2001) for a verbal n-back task. The n-back tasks had two levels of difficulty: the storage-only component and the storage-plus-updating component (2-back).

Visuospatial N-back task. For the storage only trials, the participant's task was to decide whether the stimulus (a solid black diamond with a visual angle of 2°) presented on a white background on the computer screen had the same location on the computer screen as the first one that occurred in the block of trials (see Figure 2). A small "x" warning cue was presented at the center of the screen for 200 ms at the beginning of each trial. The target stimulus was then randomly presented on the screen at one of twelve locations in an invisible 3 x 4 rectangular matrix that occupied the entire computer monitor. Responses were made via the number pad of the keyboard, and participants were instructed to press the "4" key for a yes response and the labeled "5" key for a no response. These keys were labeled "Y" and "N", respectively. The index and middle fingers of the right hand were resting on these keys throughout the task. The task was programmed so that 50% of the presented stimuli were in the original stimulus spot but were presented in a random order. The stimulus (diamond) was presented for 200 ms, followed by 4300 ms in which the participant executed the response. The experimenter led the participant through an untimed example of the task while the instructions were explained. A block of 24 practice trials preceded the task to ensure that the participant understood the instructions. All participants met the 60% accuracy criteria within the four practice blocks. Participants then engaged in three experimental blocks of 24 trials each.. Accuracy and reaction time were recorded for all trials.

Procedures were the same for the 2-back (storage-plus-updating component) trials, only the participant was now required to compare the location of the current stimulus with the location of the stimulus that occurred two trials back in the sequence. Again, the experimenter led the participant through an untimed example of the task while the instructions were explained. A block of 24 practice trials preceded the task to ensure that the participant understood the instructions. All participants met the 60% accuracy criteria within the four practice blocks. Participants then engaged in three experimental blocks of 24 trials each. Accuracy and reaction time were recorded for all trials.

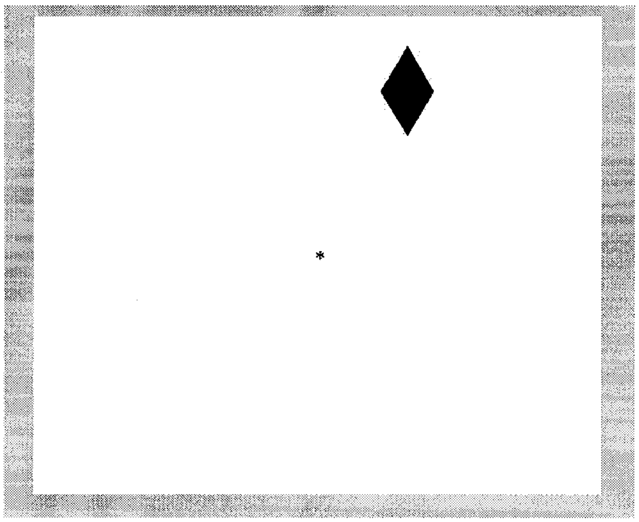


Figure 2. Example Visuospatial N-back Stimulus.

Verbal N-back task. Procedures were similar to the visuospatial n-back task, except now the participant's goal was to determine if the letter stimulus matched the one presented in the first trial of the block (storage-only component), or the one presented two trials back in the sequence (2-back, storage-plus-updating component). Stimulus letters were presented in the center of the screen in 36 pt. Ariel font drawn randomly from a set of 12 letters (See Figure 3). Number of practice and experimental trials were the same as in the visuospatial n-back task, as was timing of presentation and percentage of correct matches.

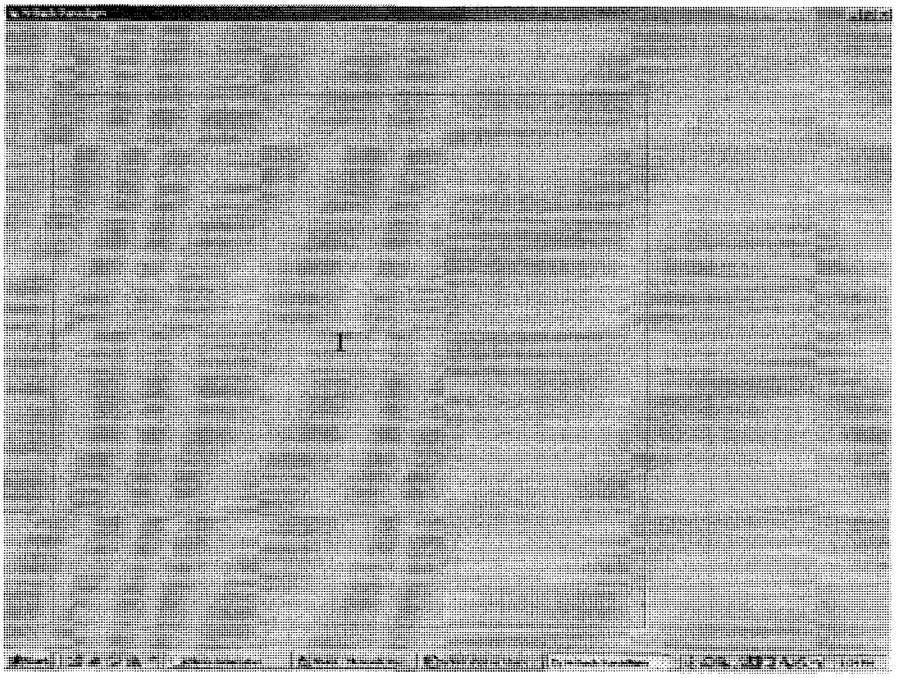
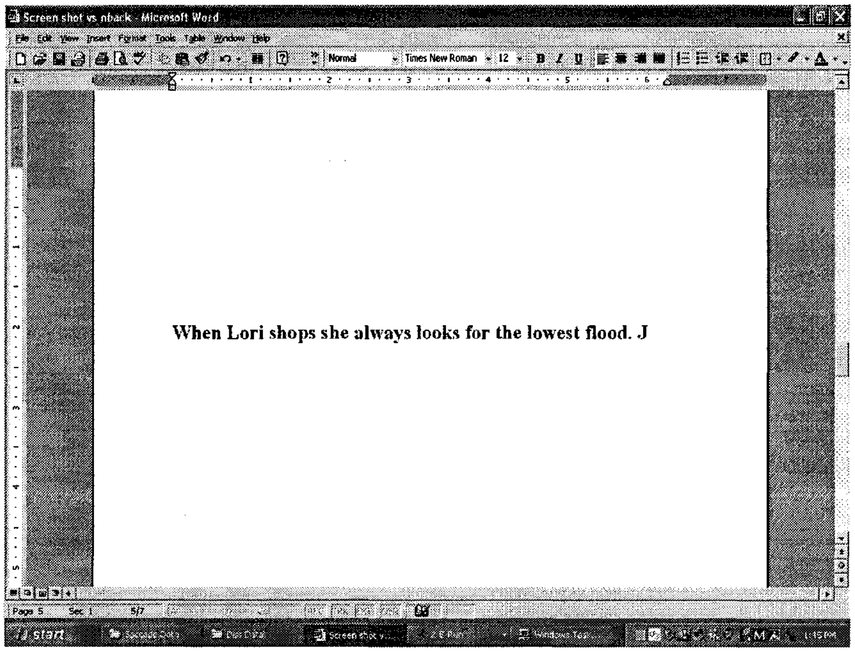


Figure 3. Example Verbal N-back Stimulus.

Span tasks. These tasks are designed to quantify how much information, whether verbal or visuospatial, the individual can store and later retrieve from memory while simultaneously processing information. For the selected tasks, the processing component involves verification of either a verbal sentence or a visuospatial matrix equation. The storage component requires maintaining either a list of letters or visuospatial locations in memory. The term "span" refers to the length of these letter lists or spatial locations.

Reading span task. This task was modeled after the classic reading span task developed by Daneman & Carpenter (1980) and modified by Kane, et al. (2004). Participants were asked to recall letters that appeared at the end of a sentence verification task. Each computer display presented either an understandable or nonsensical sentence and a to-be-remembered letter (e.g., *"We were fifty lawns out to sea before we lost sight of land. ? X"*) presented in 18 -point font (see Figure 4). Half of the sentences were sensical, half were not. Each sentence consisted of 10-15 words ($M = 12.7$ words). As soon as the sentence appeared, the participant read it aloud, verified aloud if it made sense or not, and then read the letter. As soon as the participant read the letter, the experimenter immediately pressed a key that blanked the screen for 500 ms, followed either by another sentence-letter combination or the recall cue ("???").

When presented with the recall cue, the participant wrote down each letter from the preceding set, in the order they appeared. Two practice blocks included set sizes of two sentences. All participants were able to complete both the verification and recall requirements of the task with 100% accuracy for both verification and recall for the two practice trials.

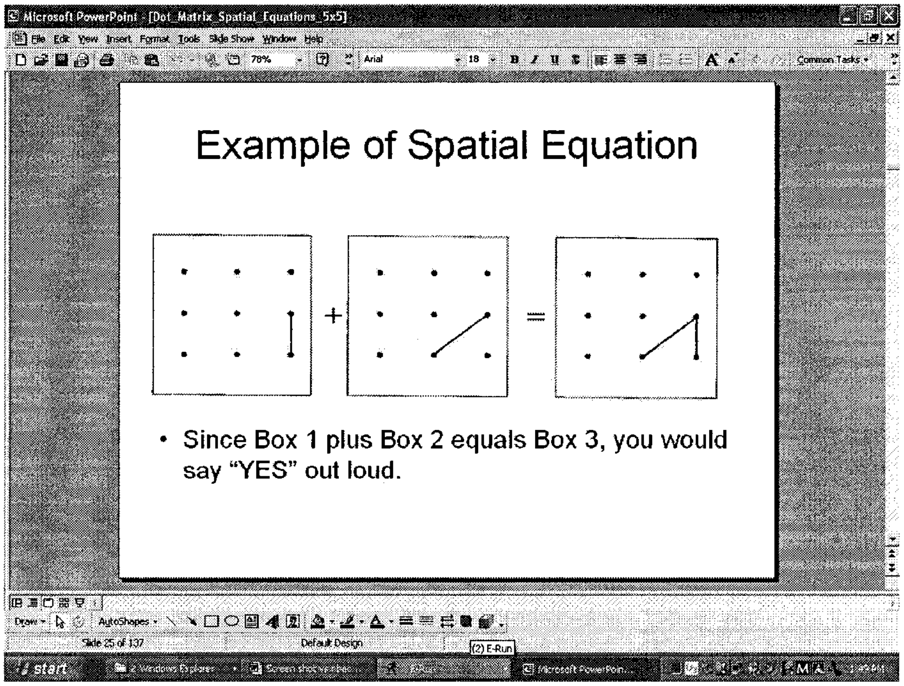


When Lori shops she always looks for the lowest flood. J

Figure 4. Example Reading Span Stimulus.

Experimental set sizes ranged from two to five sentence-letter problems, with three trials per set size (12 trials total), and they were presented in a non-systematic, but non-randomized order. Reading span was calculated as the total number of letters correctly recalled across all trials divided by the number of trials (12).

Dot matrix span task. This task was modeled after the one used by Miyake, et al. (2001). It was the visuospatial analog to the *reading span task.* In this task, the dual requirements were to verify a matrix equation while simultaneously remembering a dot location in a 5x5 grid (See Figure 5). Each trial contained a set of to-be-verified matrix equation, with each equation followed by a 5x5 grid containing one dot. In the matrix equation display, a simple addition equation is presented across two matrices and the participant will press the "4" key if the solution matrix is true or the "5" key if it is false (See Appendix H). Immediately after this response, the experimenter pressed the space bar to display the 5x5 dot matrix grid for two seconds. Following this, the participant saw either a recall cue ("???") or another matrix equation. When presented with the recall cue, the participant wrote down each dot location that was remembered from that block of trials. Two practice blocks had two matrix equations each. The participant indicated on a blank 5x5 grid where the dots were located. Participants were able to complete the task with 100% accuracy after two practice blocks. Experimental set sizes ranged from two to five matrix equations, with three trials per set size (12 trials total). Set sizes were presented in a non-systematic, non-randomized order. Dot Matrix span was calculated as the total number of correctly recalled dot locations across all trials divided by the number of trials (12).



Example of Spatial Equation

- Since Box 1 plus Box 2 equals Box 3, you would say "YES" out loud.

Figure 5. Participant Instructions for Dot Matrix Span.

EEG Apparatus and Recording Procedure

EEG was recorded from 10 mm pure tin electrodes placed according to the International 10/20 system (Jasper, 1958, see Appendix B). Recording were gathered from midfrontal (Fz), left and right midfrontal (F3, F4), and left and right parietal (P3, P4) locations, referred to both Cz and computer-derived averaged-ears references using Cz- left ear (A_1) and Cz- right ear (A_2) channels. The right mastoid served as the ground, and Fp1 recordings were used to edit and remove electro-oculographic activity. Electrical impedance was held below 5kΩ. The EEG was collected with a Neuroscan 4.2 system using Model 7181 amplifiers with the low bandpass set to 70 Hz and the high bandpass set to .5 Hz. The EEG was sampled at 256 samples per second.

Baseline EEG. Participants were instructed to sit quietly with their eyes open and focus at a blank computer screen. EEG data were recorded for 1 minute at the beginning of the experimental session, 1 minute in between the verbal and visuospatial n-back tasks, at 1 minute at the end of the n-back tasks. Data from these three time periods were averaged to arrive at the baseline EEG values.

EEG Data Analysis

Artifact editing of EEG. All EEG data were visually scored for artifacts, and all eye movements were removed from the data prior to analyses.

Data reduction of EEG. Artifact-free data were subjected to a fast Fourier transformation (FFT) to decompose the EEG waveform into sine wave components. The FFT produced estimates of absolute spectral power (in μV^2) for the theta (4-8 Hz) and alpha (8-12 Hz) frequency bands. Spectral power was converted to a power density function (in $\mu V^2/Hz$) as a measure of the average spectral power across the trial. Frontal hemispheric asymmetry was calculated as logR – logL/logR + logL = (logF4-logF3/logF4+logF3). Parietal hemispheric asymmetry was calculated as logR – logL/logR + logL = (logP4-logP3/logP4+logP3).

Experimental Procedure

Participants first completed an informed consent form and were given an overview of the experiment. Participants then completed the following screening instruments: Demographic/Medical History Questionnaire, Carpenter Physical Activity Questionnaire, Handedness Questionnaire, Visual Screening, MMSE, and Geriatric Depression Scale.

All participants completed the Vocabulary test first, followed by Digit Symbol-Coding. Digit-Symbol-Copy was the last task performed in the session. Between the Digit Symbol Coding and Copy, the saccade/antisaccade task, Reading Span, Dot Matrix Span, and Verbal/Visuospatial n-back tasks were completed. The visuospatial and verbal n-back tasks were presented in a counterbalanced order. Half of the participants performed the Verbal n-back task first; the other half performed the Visuospatial n-back task first. Participants were offered a break following the Antisaccade task and were encouraged to ask for additional breaks as necessary. Electrodes were placed on the participant's head following this break. All recording sites were lightly abraded and cleaned with isopropyl alcohol prior to electrode placement. All participants were debriefed following the conclusion of the study.

RESULTS

The following results section is organized into three main themes – participant characteristics, behavioral analyses, and electroencephalogram (EEG) analyses. Preliminary descriptive statistics were computed using participant demographics to determine if the variables of interest (age and physical activity) were confounded by any of the demographic variables. After this, the data from the study were analyzed using a series of MANOVA (multivariate analysis of variance) and ANOVA (analysis of variance) statistical procedures for both behavioral and EEG data. F-ratios for univariate analyses were computed using the Greenhouse-Geisser estimate to control for deviations from the sphericity assumption. F-ratios for multivariate analyses were computed using Wilk's Lambda.

An *a priori* alpha level of $p = .05$ was used for all analyses. Partial Eta squared was used to measure effect sizes. Correlations were executed to determine relations among processing speed, attention, and working memory tasks, as well as between Asymmetry Indices (AI) and n-back performance (accuracy and reaction time).

Participant Characteristics: Depression, Mental State, and Vocabulary

Participants were selected on the basis of specific criteria for inclusion into four groups (younger active, younger sedentary, older active, and older sedentary). Possible group differences for the variables depression, mental state, and vocabulary were examined. Depression was measured with Sheik and Yesavage's (1986) Geriatric Depression Scale; mental state with Folstein et al.'s (1975) Mini Mental State Exam; and vocabulary with the Wisconsin Adult Intelligence Scale (WAIS) vocabulary subtest.

The means and standard deviations for these three variables are presented in Table 3. Three 2 (Age) x 2 (Physical Activity- PA) ANOVAs were conducted to determine if they had any effect on depression, mental state, and vocabulary (see Table 4). Age and physical activity had no effect on depression and mental state. However, the 2 (Age) x 2 (PA) ANOVA for vocabulary yielded a significant main effect for age, F (1,76) = 20.54, $p < .001$, partial $\eta^2 = .213$. Post hoc analyses using the Tukey HSD post hoc criterion for significance indicated that although the average vocabulary scores did not differ between the older sedentary group (*M* = 50.0, *SD* = 11.16) and the older active group (*M* = 52.0, *SD* = 6.32); both older groups did score significantly higher compared to the younger sedentary group (*M* = 40.8, *SD* = 9.47) and the younger active group (*M* = 41.7, *SD* = 10.87). Thus, vocabulary was used as a covariate in the verbal working memory (Reading Span) analysis.

Table 3

Means and Standard Deviations of Younger and Older Groups for Depression[a], *MMSE*[b], *and WAIS*[c]

	Younger				Older			
	Sedentary (*n*=20)		Active (*n*=20)		Sedentary (*n*=20)		Active (*n*=20)	
Characteristic	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (years)	20.1	3.20	21.6	3.20	66.9	4.60	67.7	4.40
Depression	13.8	1.51	14.1	1.05	13.6	1.31	14.4	.88
MMSE	29.4	.68	29.3	.72	29.2	.77	29.0	.65
Vocabulary	40.8	9.47	41.7	10.87	50.0	11.16	52.0	6.32

[a] Geriatric Depression Scale- scores range from 0-15; <10 indicate probable depression. [b] Mini Mental State Exam: score range from 0-30; 23 ≤ indicate probable cognitive impairment [c] Wechsler Adult Intelligence Scale Vocabulary subtest: scores range from 0-66.

In summary, compared to the younger groups, the older groups were more educated, were retired, and were not as likely to use a computer on a daily basis. In addition, the older active group had statistically significantly higher alcohol consumption and rated their overall health as higher than the other three groups. There were no group differences for the depression and mental functioning measures; however, consistent with the literature, the older groups did perform better on the vocabulary measure. The next section will present the impact of age and physical activity on the verbal (Reading Span) and visuospatial (Dot Matrix) working memory span measures.

Table 4
Analysis of Variance (ANOVA) for Depression, Mini Mental State Exam, and WAIS Vocabulary

ANOVA	*F* (1, 76)	*P*	η^2
Depression			
Age	.03	.854	.000
Physical Activity (PA)	3.41	.069	.043
Age x PA	.852	.359	.011
Mental State			
Age	2.04	.157	.026
PA	1.23	.270	.016
Age x PA	.025	.874	.000
Vocabulary			
Age	20.54	.000***	.213
PA	.468	.496	.006
Age x PA	.071	.791	.001

*** $p < .001$.

Behavioral Analyses

The following section presents the analyses regarding working memory as measured by Reading Span (verbal), Dot Matrix Span (visuospatial), and accuracy and reaction time data from the verbal and visuospatial n-back tasks. It presents correlations among these measures, as well as the data analyses regarding cognitive processing speed and attention. Descriptive analyses indicated acceptable skewness for all behavioral variables. The variables prosaccade accuracy, antisaccade accuracy, easy and hard verbal n-back accuracy, and easy visuospatial n-back accuracy were slightly kurtotic; however, the analyses used are robust to such minor violations of the kurtosis assumption.

Age and Physical Activity Effects on Working Memory Span Tasks

A 2 (age) x 2 (PA) ANCOVA was conducted for Reading Span, using vocabulary as a covariate. A 2 (age) x 2 (PA) ANOVA was conducted for the Dot Matrix Span.

Table 5

Analysis of Covariance for Reading Span

Source	*df*	*SS*	*MS*	*F*	*p*	η^2
Vocabulary	1	4.813	4.813	44.423	.000***	.372
Age	1	2.893	2.893	26.707	.000***	.263
PA	1	.037	.037	.340	.562	.005
Age x PA	1	.252	.252	2.327	.131	.030

* $p < .05$, *** $p < .001$

As can be seen from Table 5, there was a significant main effect for age on the Reading Span, F(1,75) = 26.7, $p < .001$, partial $\eta^2 = .263$, Using the value of 46.09 for the vocabulary covariate, the analysis showed that the younger group had a reading span of 2.80 items, while the older group had a reading span of 2.37 items (see Table 6).

Table 6

Means and Standard Deviations for Number of Letters and Dot Locations Recalled for Reading Span and Dot Matrix Span as a Function of Age

	Reading Span[a]		Dot Matrix Span	
Group	*M*	*SD*	*M*	*SD*
Younger	2.80	.492	2.12	.424
Older	2.38	.492	1.71	.419

[a] Covariates appearing in the model were evaluated using the value of 46.09 for vocabulary.

Note: The mean score represents the average number of letters (dot locations) correctly recalled across the 12 sets. Sets ranged from 2-5 letters (dot locations).

Contrary to predictions, there was no significant interaction between age and physical activity for the dependent measure of Reading Span Task. The observed power estimate for this interaction was .089.

The Dot Matrix Task ANOVA yielded a significant main effect for age, *F* (1,76) = 19.12, $p < .001$, partial $\eta^2 = .201$ (see Table 7), with the younger groups recalling a greater number of dot locations (mean 2.12) than the older groups (mean 1.71). There was also a significant main effect for physical activity, *F* (1,76) = 4.20, $p = .044$, partial $\eta^2 = .052$, indicating that physically active individuals (mean 2.01) performed better on this visuospatial task than their sedentary counterparts (mean 1.82). The predicted age x physical activity interaction was not significant for the visuospatial span task, although the means were in the expected direction with the physically active younger and older participants (means -2.24 and 1.77, respectively) remembering slightly more patterns on average than the sedentary younger and older participants (means = 1.98 and 1.65, respectively). Overall observed power for this analysis was low at .122.

Table 7

Analysis of Variance for Dot Matrix Span

Source	*F*(1,76)	*p*	η^2
Age	19.12	.000***	.201
PA	4.21	.044*	.052
Age x PA	.62	.433	.008

* $p < .05$, *** $p < .001$

Verbal and Visuospatial N-back Tasks

A 2 (Age) x 2 (PA) x 2 (Task) x 2 (Taskload) x 2 (Order) GLM mixed design repeated measures MANOVA was conducted to examine the possibility of a presentation order effect on the dependent variables verbal accuracy, verbal reaction time, visuospatial accuracy, and visuospatial reaction time for the respective n-back tasks. Half of the participants had completed the verbal n-back tasks first; the other half completed the visuospatial n-back tasks first. The analysis indicated that task order did not significantly impact accuracy, F(1,70) = .36, p = .553, partial $\eta^2 = .005$ nor was did order have a significant impact on reaction time , F (1,70) = .15, p = .703, partial η^2 = .002. Thus, the order of presentation did not affect either accuracy or reaction time for the two types of tasks. There were alsono significant order interactions. Order was therefore dropped from subsequent analyses.

Separate GLM mixed design repeated measures MANOVAS were conducted to examine the between-subjects factors age and PA and the within-subjects factor taskload on the dependent variables of accuracy and reaction time for each of the n-back tasks. Thus, a 2 (age) x 2 (PA) x 2 (taskload) MANOVA was completed for verbal accuracy and reaction time, and a 2 (age) x 2 (PA) x 2 (taskload) MANOVA was completed for visuospatial accuracy and reaction time. In both analyses, age and PA were between subjects factors and taskload was a within subjects factor.

Table 8

Multivariate Analysis of Variance for Verbal N-back Task

Source	*F* (2,75)	*p*	η^2
Age	20.85	.000***	.357
Physical Activity (PA)	1.56	.218	.040
Taskload	154.44	.000***	.805
Age x PA	2.51	.088	.063
Age x Taskload	19.44	.000***	.341
PA x Taskload	.70	.498	.018
Age x PA x Taskload	1.22	.303	.031

*** $p < .001$

Verbal. The verbal GLM mixed design repeated measures MANOVA yielded a significant multivariate effect for age, F (2,75) = 20.85, p < .01, partial η^2 = .357 (See Table 8). Univariate analyses indicated that both accuracy, F (1,76) = 23.30, p < .001, partial η^2 = .235 and reaction time, F (1,76) = 24.91, p < .001, partial η^2 = .247 contributed to this multivariate effect. Table 9 presents the means and standard deviations for verbal accuracy and reaction time for the four groups. As predicted, the younger participants were more accurate on average (M = 96.5%, SD = 3.86) than the older participants (M = 91.5%, SD = 3.15). In addition, the younger participants responded more quickly on average to the stimuli (M = 768 ms, SD = 183) than the older participants (M = 946 ms, SD = 194).

Table 9
Mean Accuracy, Reaction Time, and Standard Deviations for Verbal N-back Tasks as a Function of Age and Physical Activity

	Easy Verbal				Hard Verbal			
	Accuracy[a]		Reaction Time[b]		Accuracy[a]		Reaction Time[b]	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Younger								
Sedentary	98.4	3.13	602	123	94.9	5.33	915	245
Active	98.2	3.52	594	153	94.5	3.39	958	210
Total	98.3	3.30	598	138	94.7	4.42	937	227
Older								
Sedentary	97.7	2.49	689	117	81.8	1.32	1290	283
Active	99.0	1.76	637	93	87.5	7.14	1160	267
Total	98.3	2.24	663	108	84.7	10.9	1228	279

[a] percentage correct. [b] in milliseconds

There was also a significant multivariate main effect for taskload, F (2,75) = 154.44, p < .001, partial η^2 = .805. Both accuracy, F (1,76) = 95.78, p < .001, partial η^2 = .558 and reaction time, F (1,76) = 287.386, p < .001, partial η^2 = .791 contributed to this multivariate effect. Whereas the entire sample performed at 98.3% accuracy (SD = 2.79) for the easy taskload, this accuracy decreased to 89.7% (SD = 9.69) for the harder taskload. Likewise, the entire sample had an average reaction time of 631 ms (SD = 123) for the easy taskload, this average rose to 1083 ms (SD = 253) for the harder taskload.

A significant multivariate two-way interaction was observed for age and taskload, F (2,75) = 19.44, p < .01, partial η^2 = .341. Both accuracy, F (1,76) = 32.13, p < .001, partial η^2 = .297 and reaction time, F (1,76) = 17.91, p < .01, partial η^2 = .191 contributed to this multivariate effect. Figure 6 illustrates that while the younger group's accuracy decreased from 98.3% (SD = 3.29) for the easy verbal taskload to 94.7% (SD = 4.42) for the hard verbal taskload, the older group showed an even greater decrease in accuracy (M = 98.3%, SD = 2.24 for the easy taskload, M = 84.7%, SD = 1.09 for the hard taskload)

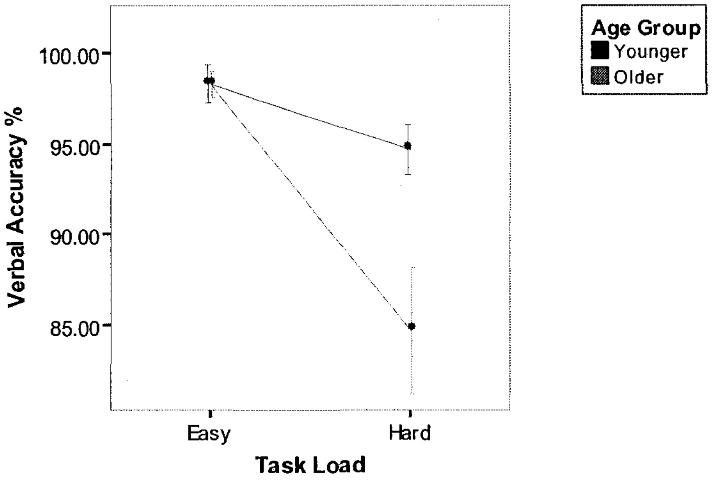


Figure 6. Mean Accuracy on Verbal N-back Task as a Function of Age and Taskload
Note. Error bars show 95% confidence intervals of the mean.

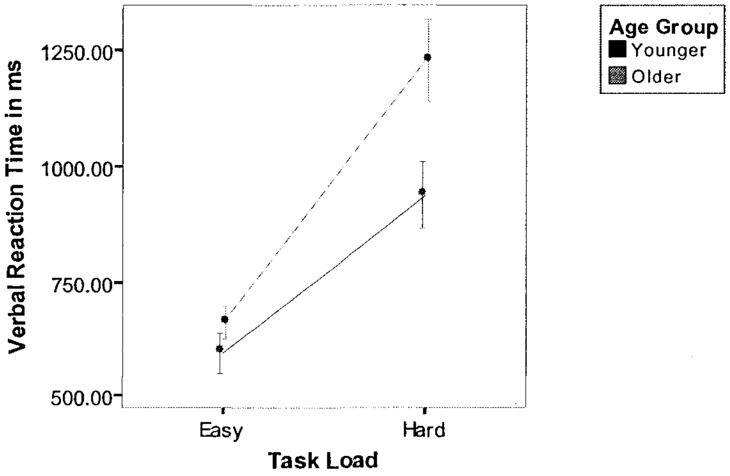


Figure 7. Mean Reaction Time (in Milliseconds) on the Verbal N-back Task as a Function of Age and Taskload. *Note.* Error bars show 95% confidence intervals of the mean.

While the younger group saw an increase in reaction time from 598 ms (SD = 137) for the easy taskload to 937 ms (SD = 226) for the harder taskload, the older group showed an even greater increase in reaction time (M = 663 ms, SD = 108 for the easy taskload and M = 1227 ms, SD = 279 for the harder taskload, see Figure 7).

The multivariate interaction for age x physical activity (PA) approached significance, F (2,75) = 2.51, p = .088, partial η^2 = .063. Univariate analyses indicated that accuracy contributed more to this near effect, F (1,76) = 3.42, p = .068, partial η^2 = .043 than reaction time, F (1,76) = 2.37, p = .128, partial η^2 = .030. It was hypothesized that the older physically active group would perform more accurately and quickly than the older sedentary group. The trend was in the expected direction. The older active group was more accurate on average (M = 93.3%, SD = 4.45) than older sedentary group (M = 89.8%, SD = 1.91). The older active group also responded on average more quickly (M = 898 ms, SD = 180) than the older sedentary group (M = 990, SD = 200).

The multivariate effects for PA and the multivariate interactions for PA x taskload and age x PA x taskload were not significant. The observed power for the three-way interaction was .249.

Visuospatial. The visuospatial GLM mixed design repeated measures MANOVA yielded a significant multivariate effect for age, F (2,75) = 20.43, p < .01, partial η^2 = .353 (see Table 10). Both accuracy, F (1,76) = 9.80, p < .01, partial η^2 = .114 and reaction time, F (1,76) = 33.10, p < .001, partial η^2 = .303 contributed to this multivariate effect. Table 11 presents the means and standard deviations for visuospatial accuracy and reaction time for the four groups. As predicted, the younger participants were more accurate on average (M = 95.2%, SD = 5.30) than the older participants (M =

90.6 %, SD = 7.4). In addition, the younger participants were responded more quickly on average to the stimuli (M = 791 ms, SD = 182) than the older participants (M = 1014 ms, SD = 223).

Table 10
Multivariate Analysis of Variance for Visuospatial N-back Task

Source	*F* (2,75)	*p*	η^2
Age	20.43	.000***	.353
Physical Activity (PA)	2.66	.078	.066
Taskload	144.60	.000***	.794
Age x PA	1.44	.244	.037
Age x Taskload	5.82	.004**	.134
PA x Taskload	2.02	.140	.051
Age x PA x Taskload	.63	.534	.017

** *p* < .01, *** *p* < .001

Table 11
Mean Accuracy, Reaction Time, and Standard Deviations for Visuospatial N-back Tasks as a Function of Age and Physical Activity

	Easy Visuospatial				Hard Visuospatial			
	Accuracy^a		Reaction Time^b		Accuracy^a		Reaction Time^b	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Younger								
Sedentary	97.4	5.14	610	92	90.4	9.95	957	230
Active	98.4	1.92	613	148	94.5	4.18	981	257
Total	97.9	3.53	612	120	92.4	7.07	969	244
Older								
Sedentary	95.0	5.70	796	195	83.0	10.60	1348	297
Active	96.2	1.76	729	168	88.2	11.53	1179	228
Total	95.6	3.73	763	182	85.6	11.07	1264	263

^{a} percentage correct. ^{b} in milliseconds

There was also a significant multivariate effect for taskload, F (2,75), 144.60, p < .001, partial η^2 = .794. Both accuracy, F (1,76) = 71.60, p < .001, partial η^2 = .485 and reaction time, F (1,76) = 249.80, p < .001, partial η^2 = .767 contributed to this multivariate effect. Whereas the entire sample performed at 96.8 % accuracy (SD = 3.63) for the easy taskload, this accuracy decreased to 89.0 % (SD = 9.07) for the harder taskload. Likewise, the entire sample had an average reaction time of 382 ms (SD = 151) for the easy taskload, this average rose to 1117 ms (SD = 254) for the harder taskload.

There was one significant multivariate two-way interaction for age x taskload, F (2,75) = 5.82, $p < .01$, partial $\eta^2 = .134$. Both accuracy, F (1,76) = 6.26, $p < .05$, partial $\eta^2 = .076$ and reaction time, F (1,76) = 6.97, $p < .05$, partial $\eta^2 = .084$ contributed to this multivariate effect. Figure 8 illustrates that while the younger group's accuracy decreased from 97.9 % (SD = 3.53) for the easy visuospatial taskload to 92.4 % (SD = 7.07) for the hard verbal taskload, the older group showed an even greater decrease in accuracy (M = 95.6 %, SD = 3.73 for the easy taskload, M = 85.6 %, SD = 11.07 for the hard taskload).

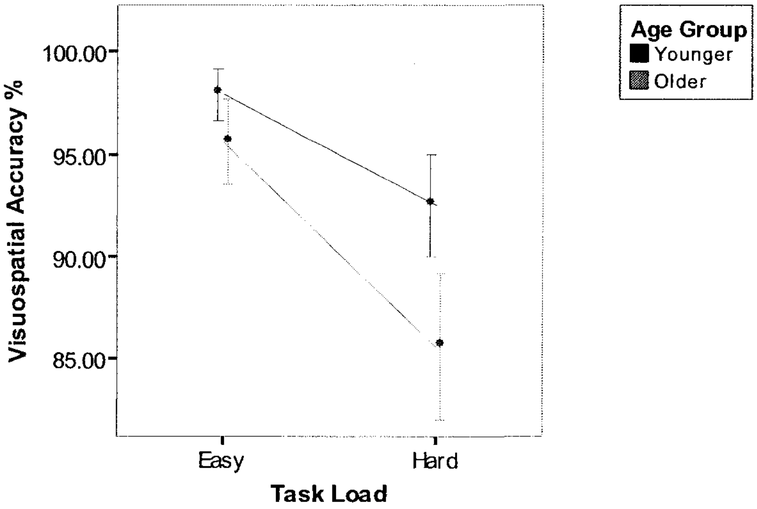


Figure 8. Mean Accuracy on the Visuospatial N-back Task as a Function of Age and Taskload
Note. Error bars show 95% confidence intervals of the mean.

Although the younger group saw an increase in reaction time from 612 ms (SD = 120) for the easy taskload to 969 ms (SD = 244) for the harder taskload, the older group showed an even greater increase in reaction time (M = 763 ms, SD = 182 for the easy taskload and M = 1264 ms, SD = 263 for the harder taskload, see Figure 9).

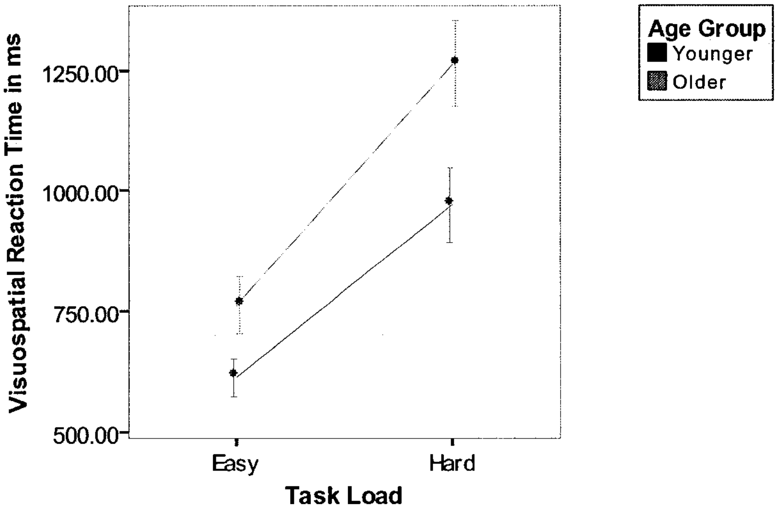


Figure 9. Mean Reaction Time (in Milliseconds) on the Visuospatial N-back Task as a Function of Age and Taskload *Note.* Error bars show 95% confidence intervals of the mean.

The multivariate effect for physical activity approached significance, F (2,75) = 2.66, p = .08, partial η^2 = .066. The multivariate interactions for age x PA, PA x taskload, and age x PA x taskload were not significant. The observed power for the nonsignificant age x taskload interaction was .223.

Correlations Among Working Memory Measures

Table 12 reports the correlation coefficients among Reading Span, Dot Matrix Span, and the Easy and Hard Verbal and Visuospatial tasks. Of importance, statistically significant positive correlations were found between Reading Span and both Hard Verbal (.366) and Visuospatial Accuracy (.222). This suggests that individuals who performed better in the Reading Span also had better accuracy for the more difficult n-back tasks. Likewise, a statistically significant correlation emerged between Dot Matrix Span and both Hard Verbal Accuracy (.508) and Hard Visuospatial Accuracy (.339). Statistically significant negative correlations were found between Reading Span and Easy Visuospatial Reaction Time (-.314), and between Dot Matrix Span and both Hard Verbal Reaction Time (-.193) and Hard Visuospatial Reaction Time (-.238). Reading Span and Dot Matrix Span were also highly correlated (.478).

Processing Speed, Attention, and Working Memory

Processing speed was calculated using the WAIS digit symbol-copy and digit symbol-coding scores. Rate of coding was subtracted from rate of copying to yield how quickly information was processed while taking motor ability into account. Thus, the processing variable represents how many milliseconds it took the participant to process each symbol. Attention was represented by the antisaccade accuracy (as percent correct) and reaction time (in milliseconds) scores. This condition required the ability to inhibit the distractor stimulus and direct attention toward the target stimulus.

Table 13 presents the correlation coefficients for all of the working memory tasks and cognitive processing speed and attention (accuracy and reaction time). Processing speed had significant positive correlations with Reading Span (.351), Dot Matrix Span (.481), Hard Verbal Accuracy (.426), Easy Visuospatial Accuracy (.296), Easy Visuospatial Reaction Time (.290), and Hard Visuospatial Reaction Accuracy (.312).

Likewise, attention accuracy had significant positive correlations with Reading Span (.296), Dot Matrix Span (.375), Hard Verbal Accuracy (.536), Easy Visuospatial Reaction Time (.325), and Hard Visuospatial Reaction Accuracy (.481). Attention

Table 12. *Correlation Coefficients for Relationships Among All Working Memory Measures*

Measure	Dot Matrix	Easy Verbal Accuracy	Hard Verbal Accuracy	Easy Verbal RT	Hard Verbal RT	Easy VS Accuracy	Hard VS Accuracy	Easy VS RT	Hard VS RT
Reading Span	.478**	.120	.366**	-.174	-.113	.001	.222*	-.314**	-.0981
Dot Matrix		.141	.508**	-.089	-.193*	.176	.339**	-.238*	-.156
Easy Verbal Accuracy			.248*	-.090	-.003	.321*	.160	-.119	-.086
Hard Verbal Accuracy				-.131	-.452**	.324*	.551**	-.284*	-.326**
Easy Verbal RT					.443**	-.009	-.006	.677**	.464**
Hard Verbal RT						-.029	-.206	.523**	.808**
Easy VS Accuracy							.554**	-.206	-.098
Hard VS Accuracy								-.182	-.269*
Easy VS RT									.534**

* $p < .05$, ** $p < .01$.

reaction time had significant positive correlations with both Easy Visuospatial Reaction Time (.243) and Hard Visuospatial Reaction Time (.237).

Table 13

Correlations Among Processing Speed, Attention, and Working Memory Tasks

	Processing Speed	Antisaccade Accuracy	Antisaccade Reaction Time
Reading Span	.351**	.296**	.045
Dot Matrix Span	.481*	.375**	-.065
Easy Verbal Accuracy	.162	.190	-.124
Easy Verbal Reaction Time	.106	.069	.162
Hard Verbal Accuracy	.426**	.536**	-.171
Hard Verbal Reaction Time	.207	.167	.087
Easy Visuospatial Accuracy	.296**	.143	.107
Easy Visuospatial Reaction Time	.290**	.325**	.243*
Hard Visuospatial Accuracy	.312*	.481**	-.147
Hard Visuospatial Reaction Time	.139	.191	.237*

**P < .05, **p < .01*

A 2(Age) x 2 (PA) GLM between subjects MANOVA was conducted to examine the between-subjects factors age and PA on the dependent variables processing speed, attention accuracy, and attention reaction time. This analysis revealed a significant multivariate effect for age, F (3,72) = 17.93, p < .001, partial η^2 = .428 (see Table 14). Univariate analyses indicated that processing speed, F (1,74) = 11.96, p < .001, partial η^2 = .139, attention accuracy, F (1,74) = 23.17, p < .001, partial η^2 = .238, and attention reaction time, F (1,74) = 45.75, p < .001, partial η^2 = .382 all contributed to this multivariate effect.

Table 14

Multivariate Analysis of Variance for Processing Speed, Attention Accuracy, and Attention Reaction Time

Source	F (3,72)	*p*	η^2
Age	17.93	.000	.428
Physical Activity (PA)	2.49	.067	.094
Age x PA	.99	.400	.040

Table 15

Means for Processing Speed, Attention Accuracy, and Attention Reaction Time

	Processing Speed[a]		Attention Accuracy[b]		Attention Reaction Time[c]	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*
Younger	667	169	94.2	4.02	641	121
Older	945	432	82.6	15.9	892	202

[a] in milliseconds

[b] percentage correct

[c] in milliseconds

As Table 15 illustrates, younger participants processed each symbol faster (M = 667 ms, SD = 169) than older participants. In addition, younger participants on average were more accurate (M = 94.2%, SD = 4.02) than the older participants (M = 82.6, SD = 15.9). Finally, younger participants were on average quicker to respond to the attention stimuli (M = 641 ms, SD = 121) than the older participants (M = 892, SD = 202). There was not a main effect for physical activity, nor an age x physical activity interaction.

Electroencephalogram (EEG) Analyses

Fifty-two participants had EEG recordings suitable for analysis. There were thirteen participants in each of the four groups – Sedentary Younger, Physically Active Younger, Sedentary Older, and Physically Active Older. The following section will present the results for theta and alpha analyses, including alpha asymmetry indices to reflect bilateral hemispheric activity.

Theta EEG Analyses

Descriptive analyses yielded acceptable values for skewness. The variables easy verbal and easy visuospatial were slightly kurtotic; however, the analyses used are robust to such minor violations of the kurtosis assumption.

Analyses of variance were conducted to determine if age, physical activity, and task load affected frontal midline theta as recorded from site Fz. First, an average baseline theta score for each participant was calculated by averaging the three 1 minute baseline measurements taken at the beginning of the n-back tasks, between the verbal and visuospatial tasks, and at the conclusion of the tasks. Each frontal midline theta score was then calculated by subtracting this baseline Fz value from the Fz value obtained during the four n-back conditions – easy verbal, hard verbal, easy visuospatial, and hard visuospatial. Therefore, delta values are reported with higher numbers indicating greater frontal midline theta activity.

Two 2 (age) x 2 (PA) x 2 (taskload) GLM mixed design repeated measures ANOVAs were conducted (one for the verbal n-back task and one for the visuospatial n-back task) to determine their influences on frontal midline theta. Age and PA were between subjects factors and taskload was a within subjects factor.

Table 16

Repeated Measures ANOVA for Midline Frontal Theta for Verbal N-back Task

Source	*df*	*SS*	*MS*	*F(1,48)*	*p*	η^2
Age (A)	1	.226	.226	.208	.651	.004
Physical Activity (PA)	1	.059	.059	.054	.817	.001
Taskload (TL)	1	1.688	1.688	6.948	.011*	.126
A x PA	1	.042	.042	.038	.845	.001
A x TL	1	.424	.424	1.745	.193	.035
PA x TL	1	.536	.536	2.208	.144	.044
Age x PA x TL	1	.014	.014	.059	.809	.001

$^*p < .05$, $^{**}p < .01$

Verbal n-back. There was a significant main effect for taskload on frontal midline theta, $F(1,48) = 6.95$, $p = .01$, $\eta^2 = .126$ (See Table 16). The average frontal midline theta delta value was .1137 (SD = .5577) for the Easy (storage only) component of the task and .3685 (SD = .9830) for the Hard (storage plus updating) component (see Table 17). This result suggested that as verbal task load increased, frontal midline theta increased for the entire sample. The observed power for the non-significant age x taskload interaction was .253. There was no main effect for age, and the predicted age x PA x taskload interaction failed to reach significance, with an observed power of .057.

Table 17

Average Midline Frontal Theta (Delta) for Verbal N-back Tasks by Age and Physical Activity

	Easy		Hard	
Group	*M*	*SD*	*M*	*SD*
Younger				
Sedentary	.017	1.0500	.566	1.3983
Active	.176	.3168	.392	.8187
Older				
Sedentary	.115	.2026	.362	1.0845
Active	.147	.2483	.154	.4606
TOTAL	.118	.5576	.369	.9380

Table 18

Repeated Measures ANOVA for Midline Frontal Theta for Visuospatial N-back Task

Source	*SS*	*MS*	*F(1,48)*	*p*	η^2
Age (A)	.940	.940	1.467	.232	.030
Physical Activity (PA)	.054	.054	.084	.773	.002
Taskload (TL)	.144	.144	1.312	.258	.027
A x PA	.000	.000	.000	.997	.000
Age x TL	.471	.471	4.282	.044*	.082
PA x TL	.014	.014	.126	.725	.003
Age x PA x TL	.422	.422	.3.835	.056	.074

$*p < .05$, $**p < .01$

Visuospatial n-back. There was a significant interaction between age and taskload on frontal midline theta, *F* (1,48) = 4.28, $p = .044$, $\eta^2 = .082$ (Table 18). This indicated that as the visuospatial task load increased, the increase in frontal midline theta was significantly greater for the younger group compared to the older group (see Table 19, Figure 10).

Table 19
Average Midline Frontal Theta (Delta) for Visuospatial N-back Task by Age and Physical Activity

	Easy		Hard	
Group	*M*	*SD*	*M*	*SD*
Younger				
Sedentary	.085	.9627	.398	1.1099
Active	.235	.3864	.340	.3687
Total	.116	.7218	.869	.8810
Older				
Sedentary	.157	.5317	-.054	.3747
Active	.052	.1917	.142	.3321
Total	.104	.3952	.644	.3565

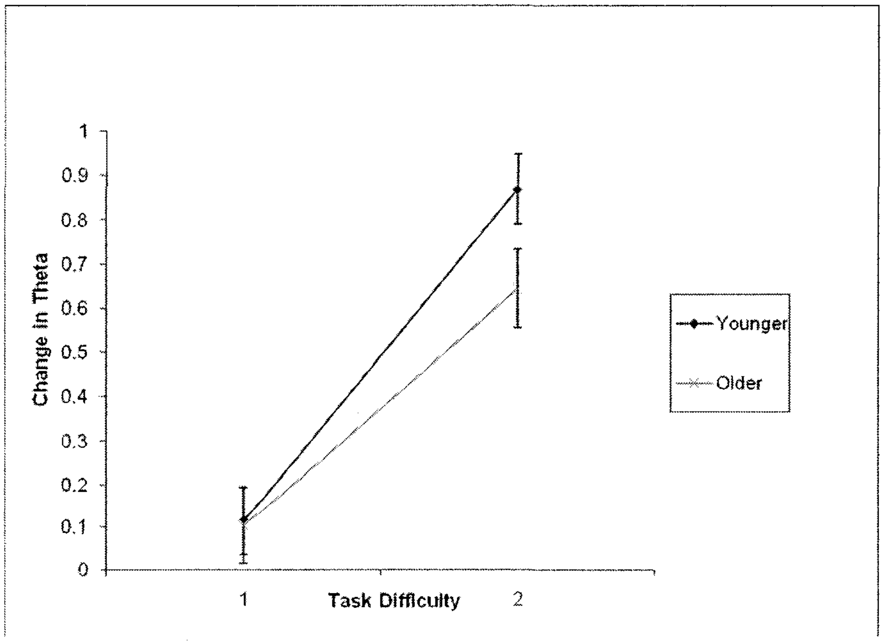


Figure 10. Change in Midline Frontal Theta as a Function of Age and Taskload.
Note: Error bars represent standard error of the mean.

Both age groups showed an increase in theta from the easy taskload to the hard; but, this increase was more pronounced in young (M = .166, SD = .7218 in the easy task to .869, SD = .8810 for the hard taskload), than in the older group (M = .104, SD = .3952 for the easy taskload; M = .644, SD = .3565 for the hard taskload). Unlike the verbal n-back task, there was no main effect for taskload on theta (observed power .202).

The predicted age x PA x taskload interaction approached significance $F = (1.48) = 3.835, p = .056, \eta^2 = .074$, with an observed power of .484 (see Figure 11). However, the interaction was not in the anticipated direction. While the older active group showed an increase in theta from .052 (SD = .1917) for the easy taskload to .142 (SD = .3321) for the harder taskload, the older sedentary group actually showed a *decrease* in theta from .157 (SD = .5317) for the easy taskload to -.054 (SD = .3747). (Note that the theta scores are changes from baseline; thus, a negative score represents that theta activity was lower during this taskload than at baseline measurements).

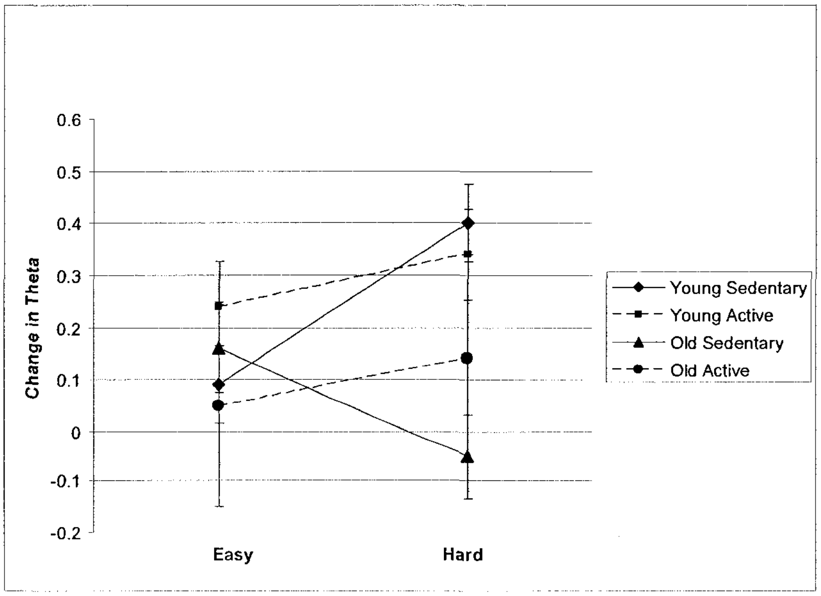


Figure 11. Change in Midline Frontal Theta as a Function of Age, Physical Activity, and Taskload for the Visuospatial N-back Task. *Note:* Error bars represent standard error of the mean.

Correlations among n-back accuracy, reaction time, and theta. Two correlation analyses were conducted to determine if relationships existed between effort (frontal midline theta) and the behavioral measurements of accuracy and reaction time (see Tables 20 and 21). No such relationship existed during either the verbal or visuospatial n-back tasks.

Table 20
Correlations Among Verbal N-back Accuracy, Reaction Time, and Theta

	Accuracy		Reaction Time	
	Easy	Hard	Easy	Hard
Easy Theta	-.017	-.083	.059	.061
Hard Theta	.063	.010	.084	-.048

Table 21
Correlations Among Visuospatial N-back Accuracy, Reaction Time, and Theta

	Accuracy		Reaction Time	
	Easy	Hard	Easy	Hard
Easy Theta	-.010	-.102	.094	-.113
Hard Theta	.025	.022	.075	-.110

Alpha Analyses

Similar to the theta analyses, an average baseline alpha score for each participant at each site (F3, F4, P3, P4) was calculated by averaging the three 1 minute baseline measurements taken at the beginning of the n-back tasks, between the verbal and visuospatial tasks, and at the conclusion of the tasks. Each alpha score was then calculated by subtracting the alpha values at each site obtained during the four n-back conditions – easy verbal, hard verbal, easy visuospatial, and hard visuospatial from the respective average baseline alpha value for that site. This was done in to keep the values positive, as alpha is generally higher during rest than when the brain is actively engaged. Therefore, delta values are reported with lower values reflecting less alpha, which is indicative of greater activation at that site.

Alpha asymmetry indices were calculated for the frontal sites [(F4-F3)/(F4+F3)] and parietal sites [(P4-P3)/(P4+P3)]. These indices were calculated for both verbal and visuospatial tasks, at both task loads (easy, hard). Thus, eight alpha asymmetry indices were calculated: Easy Verbal Frontal (EVF), Easy Verbal Parietal (EVP), Easy Visuospatial Frontal (EVSF), Easy Visuospatial Parietal (EVSP), Hard Verbal Frontal (HVF), Hard Verbal Parietal (HVP), Hard Visuospatial Frontal (HVSF), and Hard Visuospatial Parietal (HVSP).

Positive asymmetry indices (AI) indicate greater alpha power in the right hemisphere, which actually reflects greater activation in the left hemisphere. Conversely, negative asymmetry indices indicate greater alpha power in the left hemisphere, which corresponds with greater activation of the right hemisphere. In other words, a positive asymmetry index suggests greater left brain activity and a negative index suggests greater right brain activity. An asymmetry index of zero is indicative of equal, or bilateral, activation across the hemispheres – neither hemisphere is dominant for the task.

Descriptive analyses yielded acceptable skewness for most variables, but higher than acceptable skewness for EVP4 (2.42), HVP3 (2.48), HVP4 (2.47), and HVSP4 (2.32). Nine of the sixteen variables demonstrated unacceptable kurtosis values. Thus, box plot analyses were conducted to identify potential outliers. After outlier data (more than two standard deviations from the young/old, sedentary/active group mean) were removed, there were 48 participants with acceptable data for EVSP4; 49 for HVSF3; 50 for HVP3, HVP4, HVSF4, HVSP3, and HVSP4; 51 for EVF3, EVF4, EVP3, 3VP4, HVF3, and HVP4; and all 52 for EVSF3, EVSF4, AND EVSP3. Following subtraction of these outliers, all values had acceptable skewness. Consistent with the methodology recommended by Davidson et al. (1990), all remaining data points were log transformed. This final step yielded acceptable skewness and kurtosis for all sixteen variables.

Separate GLM mixed design repeated measures ANOVAs were conducted to examine the between-subjects factors age and PA and the within-subjects factors taskload and site on the dependent variable asymmetry index for the verbal and visuospatial n-back tasks.

Verbal. The 2 (Age) x PA (2) x Taskload (2) x Site (2) mixed design repeated measure ANOVA yielded no significant main effects or interactions for asymmetry indices (see Table 22, means and standard deviations in Table 23). As can be seen, the analyses for the variable age and its interactions with both physical activity and taskload were not very powerful (.183, .124, and .062, respectively).

Table 22

Analysis of Variance for Asymmetry Indices for the Verbal N-back Task

Source	F (1,38)	*p*	η^2	Observed power
Age	1.16	.288	.030	.183
Physical Activity (PA)	.16	.692	.004	.067
Taskload (TL)	.02	.881	.001	.052
Site	2.13	.153	.053	.296
Age x PA	.66	.422	.017	.124
Age x TL	.11	.747	.003	.062
Age x Site	.23	.634	.006	.075
PA x TL	.21	.648	.006	.073
PA x Site	.95	.337	.024	.158
TL x Site	.01	.931	.000	.051
Age x PA x TL	.41	.528	.011	.095
Age x PA x Site	1.25	.271	.032	.193
Age x TL x Site	.01	.941	.000	.051
PA x TL x Site	1.08	.305	.028	.173
Age x PA x TL x Site	.41	.526	.011	.096

Table 23

Asymmetry Indices for Frontal and Parietal Sites for the Verbal N-back Task

	Easy				Hard			
	Frontal (EVF)		Parietal (EVP)		Frontal (HVF)		Parietal (HVP)	
Group	M	SD	M	SD	M	SD	M	SD
Younger								
Sedentary	.33	3.370	.62	3.785	-.38	5.126	.30	2.811
Active	.44	.997	-.81	3.287	.89	2.740	-.52	2.807
Older								
Sedentary	-.18	1.737	-1.67	4.119	-.50	1.983	-.81	1.606
Active	-.10	.892	-.31	2.015	.59	1.460	-.76	1.906

It was hypothesized that younger groups (sedentary and active) would show positive asymmetry indices for EVF and EVP. This would be demonstrative of left hemisphere activity for the easy verbal task. It was also hypothesized that as the task became more difficult (hard verbal taskload) the younger participants would show an increase in bilateral activation (asymmetry indices approaching zero). It was further hypothesized that the older groups (sedentary and active) would show greater bilateral activation (asymmetry indices approaching zero), at both the easy and hard taskloads for the verbal tasks. The asymmetry indices shown in Table 23 suggest that the sedentary groups showed bilateral activation at both frontal and parietal sites for the easy verbal, with the exception of the younger active group showing a tendency toward greater right hemisphere activation at the parietal sites (M = -.81, SD = 3.287). This pattern of bilateral activation persisted when the task became more difficult, with the exception now being the younger active group switching to greater left activation (M = .89, SD = 2.740) for the frontal sites. The older active group showed frontal and parietal bilateral activation for the easy taskload of the verbal task. However, as the taskload became more difficult, the frontal sites continued with bilateral activation (M=.59, SD = 1.460) but the parietal sites showed a trend toward right hemisphere activation (M=-.76, SD = 1.906). The older sedentary group showed bilateral activation at the frontal sites for both the easy and hard taskloads. However, the parietal sites for the easy taskload showed a pronounced dependence on right hemisphere activity (M = -1.67, SD = 4.119), and a slight leaning toward right hemisphere activity as the taskload increased (M = -.76, SD = 1.906).

Visuospatial. The visuospatial 2 (Age) x 2 (PA) x 2 (Taskload) x 2 (Site) mixed design repeated measure ANOVA yielded a significant effect for site, F (1,35) = 8.06, p < .01, partial η^2 = .187 (see Table 24). This suggests that the asymmetry indices of the frontal sites are significantly different than those of the parietal sites, regardless of age and taskload. From Table 25 it can be seen that, overall, the parietal sites showed greater negative asymmetry indices, indicative of right hemisphere activation.

Table 24
Analysis of Variance for Asymmetry Indices for the Visuospatial N-back Task

Source	F (1,35)	*p*	η^2	Observed power
Age	3.05	.089	.080	.397
Physical Activity (PA)	1.42	.242	.039	.212
Taskload (TL)	3.03	.091	.080	.394
Site	8.06	.007**	.187	.788
Age x PA	1.57	.218	.043	.230
Age x TL	1.54	.223	.042	.226
Age x Site	.09	.771	.187	.788
PA x TL	.20	.656	.006	.202
PA x Site	.76	.388	.021	.763
TL x Site	1.74	.196	.047	.249
Age x PA x TL	4.13	.050*	.105	.506
Age x PA x Site	.18	.676	.005	.069
Age x TL x Site	.29	.595	.008	.287
PA x TL x Site	.02	.890	.001	.020
Age x PA x TL x Site	.79	.379	.022	.794

*$p < .10$, **$p < .01$

There was also a significant three-way interaction between age, physical activity, and taskload, F (1,35) = 4.13, p < .05, partial η^2 = .105. As illustrated in Figure 12, three of the groups showed bilateral activation for the easy and hard taskloads. The younger sedentary showed bilateral activation at both the easy taskload (M = -.46, SD = 1.758) and the hard taskload (M = -.610, SD = 1.948) as did the older sedentary group (M = -.03, SD = 1.962 for the easy taskload, M = -.625, SD = 1.454 for the hard taskload, and the active group (M = -.45, SD 2.620 for the easy taskload, M = -.10, SD = 2.512 for the harder taskload). However, the younger active group showed a pattern of slight right hemisphere activation (M = -.78, SD = 1.945) for the easy taskload and a strong dependence on the right hemisphere for the hard taskload (M = -2.50, SD = 2.870).

Table 25
Asymmetry Indices for Frontal and Parietal Sites for the Visuospatial N-back Task

	Easy				Hard			
	Frontal (EVSF)		Parietal (EVSP)		Frontal (HVSF)		Parietal (HVSP)	
Group	M	SD	M	SD	M	SD	M	SD
Younger								
Sedentary	-.22	1.518	-.67	1.998	.02	2.430	-1.23	1.465
Active	-.69	1.509	-.87	2.398	-1.45	2.810	-3.54	2.929
Older								
Sedentary	-.11	1.497	.16	2.426	-.10	1.426	-1.15	1.482
Active	.21	1.277	-1.10	3.962	.46	3.568	-.66	1.455

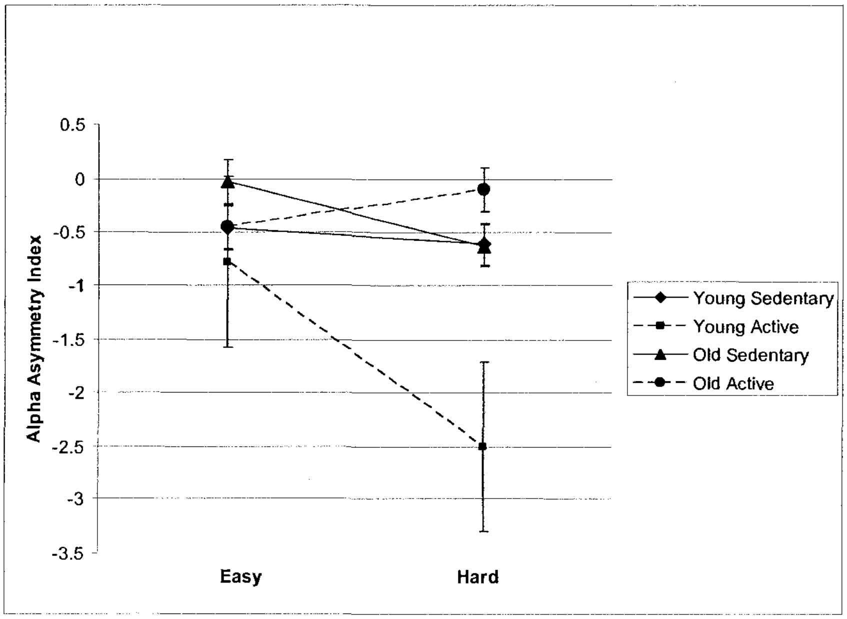


Figure 12. Hemispheric Activation as a Function of Age, Physical Activity, and Visuospatial Task Difficulty
Note: Error bars represent standard error of the mean.

It was hypothesized that younger groups (sedentary and active) would show negative asymmetry indices for EVSF and EVSP, indicative of greater right hemisphere activation. Table 25 indicates that the younger sedentary group showed a trend toward greater right parietal activation (M = -.67, SD = 1.998) for the easy visuospatial task, but not in the frontal location (M = -.22, SD = 1.518). The younger active group also showed this trend toward greater right frontal activation (M = -.69 , SD = 1.509) and parietal (M = -.87, SD = 2.398) sites for the easy visuospatial task.

It was also hypothesized that as the task became more difficult (hard visuospatial taskload) the younger participants would show an increase in bilateral activation (asymmetry indices approaching zero). This was only true for the younger sedentary group at the frontal sites (M = .02, SD = 2.430). This group's parietal asymmetry index, along with the young active group's frontal *and* parietal sites, indicated a strong dependence on the right hemisphere as task difficulty increased.

It was further hypothesized that the older groups (sedentary and active) would show greater bilateral activation (asymmetry indices approaching zero), at both the easy and hard taskloads for the visuospatial tasks. The older sedentary group showed bilateral activation at the frontal sites (M = -.11, SD = 1.479) and the parietal sites (M = .16, SD = 2.426) for the easy visuospatial taskload. However, when the task became more difficult, the older sedentary maintained bilateral activation at the frontal sites (M = -.11, SD = 1.426) but stronger right activation (M = -1.14, SD = 1.482) at the parietal sites. Conversely, the older active group showed similar patterns of bilateral activation for the frontal sites (M = .21, SD = 1.277 for the easy visuospatial taskload, M = .46, SD = 3.568 for the hard taskload), but an opposite pattern arose for the parietal sites. The older active group actually showed more right hemisphere activation for the easy taskload (M = -1.10, SD = 3.962), but this trended toward more bilateral activation for the hard taskload (M = -.66, SD = 1.455).

Correlations Among Asymmetry Indices, N-back Accuracy, and Reaction Time

Two correlational analyses were conducted to determine if relationships existed between hemispheric activation (asymmetry indices) and the behavioral measurements of accuracy and reaction time (see Tables 26 and 27). There was a negative correlation between alpha asymmetry at the frontal sites and performance reaction time during the easy verbal task. This suggests that as the alpha index becomes more positive (indicating greater left hemisphere activity), reaction time decreases. Thus, when participants favored the left hemisphere, which is generally associated with verbal processing, reaction time was faster. However, there was also a negative correlation between alpha asymmetry at the parietal sites and performance accuracy during the easy verbal task. This suggests that as the alpha index becomes more positive (indicating greater left hemisphere activity), performance actually decreased. Finally, there was a positive correlation between alpha asymmetry at the frontal sites and performance reaction time during the easy visuospatial task load. This suggests that as the alpha index becomes more positive (indicating greater left hemisphere activity), reaction time also increased. Thus, when participants favored the left hemisphere, which is *not* generally associated with visuospatial processing, it took them longer to respond to the stimuli.

Table 26

Correlations Among Alpha Asymmetry Indices and Verbal N-back Accuracy and Reaction Time

	Accuracy		Reaction Time	
	Easy	Hard	Easy	Hard
EVF	-.155	-.028	-.314*	-.048
EVP	-.260	.108	-.096	-.090
HVF	-.029	.207	-.077	-.130
HVP	-.401**	.043	-.147	-.213

* p < .05, ** p < .01

Table 27

Correlations Among Alpha Asymmetry Indices and Visuospatial N-back Accuracy and Reaction Time

	Accuracy		Reaction Time	
	Easy	Hard	Easy	Hard
EVSF	-.006	-.152	.293*	.017
EVSP	-.083	-.091	-.011	-.060
HVSF	.060	.167	-.207	-.149
HVSP	-.264	-.061	-.054	-.050

* $p < .05$, ** $p < .001$

DISCUSSION

Objectives of the Current Study

The primary goal of the current study was to investigate whether physical activity in older individuals offsets the decline in working memory that is typically associated with aging. The second objective was to investigate the effects of age and physical activity on alpha and theta brainwave activity as a function of task load for the n-back tasks. The third objective was to investigate physical activity's relationships with both information processing speed and inhibitory function, which is related to attentional mechanisms. Both of these psychological processes have been hypothesized to influence working memory. It was hypothesized that if physical activity did ameliorate the effects of cognitive aging, perhaps the reason why could be elucidated by studying these relationships.

Behavioral Indices

Span tasks. Based on previous research (Salthouse, 1992), it was hypothesized that there would be a main effect for age on both verbal (reading span) and visuospatial (dot matrix) tasks. This hypothesis was supported. Younger participants outperformed their older counterparts on both the verbal and the visuospatial span tasks. However, physical activity did not seem to affect this relationship. Based on the body of literature regarding physical activity and cognitive health (Colcombe et al., 2003: McCauley et al., 2004; Newsome & Kemps, 2006), it was hypothesized that the older physically active group would outperform the older sedentary group on both the span tasks. It is possible that the measures in the present investigation were not sensitive enough to capture differences that may have been there. It is also possible that the effect sizes are much smaller than were anticipated and would therefore have required a larger sample size to detect. The observed power statistics for the present study were much lower than were predicted, based on previous studies. These low observed power statistics suggest that a larger sample size would have been necessary to detect any potential differences between the older sedentary and older physically active groups on these working memory tasks. An additional explanation for not finding the predicted effect of physical activity may have been unreliability of self-reports for patterns of physical activity. Indeed, Barnes, Yaffe, Satariano, & Tager (2003) question the validity of this methodology. Although concentrated efforts were made in the current study to correctly classify individuals, it may be that self-report is not a valid indicator of physical fitness. In other words, it is possible that some individuals presented themselves more or less active than they really were, thus diluting a possible interaction between age and physical activity. Even if all participants did correctly classify themselves as either sedentary or physically active, this does not distinguish between the *behavioral* variable of physical activity and the *biological* variable of aerobic fitness. Indeed, Etnier, Sibley, Pomeroy, and Kao (2003) found that aerobic fitness, but not physical activity, predicted a significant portion of the variance in their reaction time measures.

Further analysis of the reliability of the self-report measure of physical activity and its relationship with aerobic fitness can not be achieved with the present data. However, as previously stated, support for the hypothesized negative impact of age on working memory span performance was observed on both the verbal and visuospatial working memory tasks. These findings are consistent with the literature and provide support for the validity of the current methodology used to administer the working memory span tasks (Salthouse & Babcock, 1991; Stine & Wingfield, 1987).

It was thought that the physically active older individuals would perform as well as the younger group on both spans tasks, and that only the sedentary older adults would show the age-related decline in working memory. As this was not the case, the results of this study contradict earlier research in this area. The work of the Chozko-Zjako (1991) suggests that tasks requiring a great deal of effortful processing would demand greater attentional capacity and thus show more age-related decline. Research by Spirduso (1980), Offenbach et al. (1990), and van Boxtel et al. (1997) all indicate the presence of an aerobic fitness effect on cognitive processing. However, it must be remembered that Spirduso and Offenbach measured reaction time and choice reaction time, not letter or location recall. Likewise, van Boxtel also did not utilize span tasks in their paradigm; rather, they measured Stroop color/word interference and concept shifting tasks. While these are all arguably attention demanding tasks, they do not involve the storage, rehearsal, and updating requirements of the span tasks. These characteristics would seem to involve a high demand on executive functioning. According to Kramer et al.'s (1999) "selective influence" hypothesis, these processes would be augmented by enhanced fitness. It must be noted again, though, that these researchers did not use span tasks to approximate working memory. Rather, they measured task switching, response compatibility, and stopping.

N-back task performance. The impact of age on working memory performance was further supported in the current investigation by performance on the n-back tasks. Both accuracy and reaction time on these tasks were negatively affected by age. As expected, there was no age difference in performance for the easy version of the n-back task, when the cognitive demands involved storage of only one letter or visuospatial location. However, when the task became more difficult, the younger individuals made fewer errors than older individuals for both the verbal and visuospatial n-back tasks. Accuracy declined for all participants as task load increased from storage only to storage plus updating. However, the presence of an interaction between age and taskload suggests that the older groups had more difficulty coping with the increased working memory requirement. Effects of age were also evident for n-back reaction time. As hypothesized, the younger groups responded more quickly at both the storage only and storage plus updating levels of difficulty. Similar to accuracy, reaction time increased for all participants as task load increased, as hypothesized. This increase in reaction time was differentially more pronounced for the older groups relative to the younger groups as taskload increased. This differential impact of task complexity was exhibited by the multiple age with taskload interactions for both the verbal and visuospatial n-back tasks.

The two difficulty (taskload) levels of the n-back task differentiate between an easy, storage only condition and a harder, storage plus updating condition, which places a greater demand on executive functioning. Similar to previous research (e.g., Gevins & Smith, 2000), the present study showed that as working memory task difficulty increased, performance and reaction time were impacted in the anticipated manner. As the task became more challenging, verbal accuracy decreased, and both verbal and visuospatial reaction time increased. Thus, the demands of updating the content of working memory had two effects. Accuracy suffered, and processing and response time was slower. Sometimes accuracy can be maintained through slower, more deliberate processing, but this was not the case in this study.

As predicted, the drop in accuracy and increased reaction time was greater for the older groups than the younger groups. This is consistent with the research of McEvoy et al. (2001), who found that younger participants responded more quickly and accurately than older participants in a visuospatial 2-back task. In the present study, the older participants were negatively affected by the increase in task difficulty for verbal and visuospatial accuracy and verbal reaction time.

In summary, the interaction between age and taskload emerged for both verbal and visuospatial tasks, for both accuracy and reaction time. These findings are consistent with what Verhaeghen (2000) has termed as parallelism in cognitive processing between young and between age and older adults. His argument is that processing differences between younger and older persons are quantitive, rather than qualitative, in nature. By this he means that the types of processes involved, and their sequencing, may be well preserved with age, but they are constrained by general efficiency problems. As researchers have not yet found a way to rigorously test this notion, it can be thought of as an assumption that can be supported by finding interactions between age and task difficulty. Following this theoretical model, it is possible that the older group in this study was using the same cognitive *processes* as the younger group for the more difficult 2-back condition. The difficulty may lie in the fact that these processes require more cognitive resources, such as attentional resources, that are less readily available for the older group.

The two span and two n-back tasks were all chosen to assess working memory. Were they tapping into the same working memory construct? Reading span and Dot matrix span were highly correlated. Both Reading span and Dot matrix span were correlated with the accuracy scores for the hard verbal and visuospatial n-back tasks. Thus, it would appear that at least the more difficult levels of the n-back tasks were systematically related to the construct of working memory. This observation provides a degree of convergent validity for the tasks chosen for inclusion in this study. Conversely, divergent validity was evidenced in that performance on the WAIS vocabulary test, which represents crystallized intelligence, was not correlated with verbal and visuospatial span tasks. Consistent with previous research (e.g., Babcock & Salthouse, 1990), the older group in this study displayed stronger performance in regard to crystallized intelligence compared to the younger group.

Similar to the span tasks, but contrary to our predictions, the physically active older individuals did not outperform the sedentary older individuals on the more difficult n-back tasks, in terms of either accuracy or reaction time. Again, the observed power estimates for these three-way interactions were extremely low, possibly indicating that the effect sizes were smaller than anticipated and thus would have required a larger sample size for detection. Conversely, the issue may once again have stemmed from the limitation of using self-reported physical activity versus laboratory measured aerobic fitness has already been addressed. It can be argued that the n-back paradigm has respectable validity, as numerous researchers (McEvoy et al., 2001; Reuter-Lorenz et al. 2000), have found age-related differences with this task, including the present study. Alternatively, one explanation for our failure to find the anticipated relationship of physical activity and working memory performance involves the time of day as an influential factor for studying cognitive aging. Recently, Bugg, DeLosh, & Clegg (2006) found that the working memory performance of older sedentary adults declined significantly from morning to evening testing sessions. This time of day effect was not evidenced for the physically active group of older adults. The researchers conclude that physical activity can stave off mental fatigue as the day progresses. The majority of older participants, both sedentary and physically active, completed the current study between the hours of 8 am through noon. This was an artifact of scheduling the experimental sessions at the convenience of the participants, and the majority of them selected morning sessions. Thus, it is possible that the anticipated age, physical activity, and taskload interactions were not found because the sedentary group was at their peak performance in relation to time of day. It is therefore recommended that future research in this area take time of day into consideration as a potential confounding variable.

It can further be argued that previous published studies looking at the fitness/cognitive maintenance relationship have generally relied on tasks other than the n-back paradigm (Chozko-Zajko, 1990; Kramer et al., 1999; Shay & Roth, 1992). A thorough review of the literature indicates that the present study is the only cognitive aging/physical fitness study to employ n-back tasks as working memory constructs. Therefore, it is possible that physical fitness does not impact the aspect of working memory assessed by these tasks. It will take a series of studies adopting this methodology to determine if an interaction truly exists.

Neurophysiological Indices

The second objective of this study was to evaluate age related differences in EEG among younger and older, sedentary, and active individuals. Specifically, frontal midline theta and alpha asymmetry patterns in response to performing the n-back tasks were analyzed.

Frontal midline theta. It has been fairly well documented that frontal midline theta increases as a function of task difficulty (Gevins & Smith, 2000: Jonides & Smith, 1997). According to Posner and Peterson (1990), fmΘ is enhanced in tasks with greater working memory demands. The results from the current study support this notion for the verbal, but not visuospatial measures. For the verbal task, the expected increase in fmΘ was witnessed as the task increased from the storage only to the storage plus processing demands. Thus, the findings of McEvoy et al (2001) were supported. It was hypothesized that only the older physically active participants, but not the sedentary older participants, would demonstrate this increase in fmθ. Thus, the present study sought to expand upon previous research by teasing out the differences in fmθ between sedentary and physically active older individuals. In actuality, no differences in fmθ were found between the older sedentary and active groups while performing the n-back tasks. Although the interaction among age, physical activity, and taskload approached significance, the trend was not in the expected direction. The older active group did show an increase in fmθ as taskload increased, but the older sedentary group showed a *decreased* in fmθ as the taskload increased. Because theta was measured only at the frontal midline site, it cannot be determined whether this group was showing greater activation in other areas to compensate for the inability to use this region, which is generally associated with increased attention and focus. A recent review by Reuter-Lorenz and Cappell (2008) suggests that older individuals may *overactivate* certain brain regions in order to maintain performance levels. This may be interpreted as supporting the compensatory model of cognitive brain aging.

Alpha asymmetry. Brain activity in the alpha range generally represents a restful, more relaxed state. Thus, a decrease in alpha represents a more active, focused brain state. Asymmetry indices permit the determination of which side of the brain is more activated during a given task.

For the younger participants, the hypotheses for hemispheric lateralization of function for the easy tasks were not entirely supported. Previous research using PET technology indicated that verbal storage tasks elicited a left lateralization pattern and a right lateralization pattern for visuospatial storage tasks (Smith et al. 1996; Reuter-Lorenz et al, 2000). The present study sought to duplicate these lateralization effects using EEG measurements, rather than PET. For this reason, the same n-back methodology from the Smith et al. (1996) and Reuter-Lorenz et al. (2000) studies were used.

Based on this, it was hypothesized that the younger groups would show a positive asymmetry index for the verbal storage task and a negative asymmetry index for the visuospatial task. The results did not support this hypothesis. Although positive, the frontal asymmetry index suggests bilateral activation (.39). The parietal asymmetry index for the younger group would also be considered bilateral activation (-.10).

The younger groups also did not display the expected negative asymmetry indices at both the frontal and parietal sites for the easy, storage only visuospatial condition. Rather, a pattern of bilateral activation (asymmetry indices approaching zero) were observed at both the frontal and parietal sites for the easy visuospatial condition. These observations deviate from the work of Smith et al. (1996) and Reuter-Lorenz (2000).

The hard condition of the n-back tasks places a much greater demand on cognitive resources. Specifically, executive resources come into play. Accordingly, Smith and Jonides (1999) found a pattern of bilateral activation under the more difficult n-back conditions (2- and 3-back). Again, the current study sought to replicate, based on the findings of McEvoy (2001) these PET results using the EEG.

The results of this part of the study somewhat mirrored the work of Smith et al. (1996) and McEvoy et al. (2001). As the verbal task demands increased from storage only to storage, rehearsal, and updating, alpha activity decreased at all four sites – F3, F4, P3, and P4, indicating that the younger group used a strategy dependent on both frontal (rehearsal) and parietal (storage) areas. Further, the frontal and parietal asymmetry indices approached zero for the hard verbal. Thus, the increase in task load generated a response indicative of the hypothesized bilateral activation.

However, as confirming as these results were for the verbal task, they were not duplicated for the visuospatial task. The younger group showed bilateral activation for both the easy *and* hard visuospatial task. This lack of hemispheric lateralization does not support the earlier cited work of Reuter-Lorenz (2000). One reason for this may be the lower spatial resolution of EEG compared to PET technology. In addition, the novelty of the visuospatial task may have elicited a recruitment of additional brain regions than typically found for visuospatial tasks.

In conclusion, some of the hypotheses regarding alpha were supported for the younger group. Hemispheric specialization (left verbal, right visuospatial) was not strongly observed at the easy level. At the harder level, activity became bilateral at both the frontal and parietal sites for the verbal task. The hard visuospatial tasks continued to elicit a strong right activation pattern. It was hypothesized that alpha would decrease at the parietal, but not frontal sites as task difficulty increased. It was found that alpha decreased at both parietal and frontal sites, indicating that all areas were recruited for the more difficult task demands. One major exception to this pattern is found in the young physically active adults who exhibited significantly greater right hemispheric activation in the more demanding visuospatial n-back task relative to their performance in the easy n-back task and relative to the other age and activity level groups. At this point, it is difficult to explain this observation.

Previous research seems to indicate a bilateral pattern of activity among older participants even for the easier, storage only version of the task (Reuter-Lorenz et al., 2000; Reuter-Lorenz & Stanczak, 2000; Cabeza, 2000). Again, these studies utilized PET imagery, while the current study sought to replicate these results using the EEG.

This study also builds on previous literature because it integrates the physical activity/cognitive maintenance component. The previously cited experiments regarding alpha activity did not differentiate between sedentary and physically active older participants. In all likelihood, the participants probably represented a range of physical activity involvement. Given the novel and exploratory nature of this study, a starting point needed to be determined.

Thus, it was hypothesized that the alpha activity of the sedentary older individuals from this study would mirror the bilateral activation observed in the Reuter-Lorenz studies, even for the easier, storage only tasks. Following Kramer et al.'s (1999) "selective influence" executive control/fitness hypothesis, it was thought that the alpha activity of the active older individuals would more closely resemble that of the younger group. That is, it was hypothesized that the physically active older participants would show hemispheric lateralization for the easy verbal and visuospatial taskload; however, bilateral activation, as represented by a near zero asymmetry index, would appear for the difficult task load, as it had been hypothesized for the younger group.

The results did not fall into exactly such a neat pattern. The older sedentary group did show bilateral activation at the frontal site for the easy verbal task and both the frontal and parietal sites for the easy visuospatial tasks. However, this group showed strong right hemisphere activation at the parietal site for the easy verbal task, which is difficult to interpret.

When the verbal task became hard, bilateral activation was observed in both the frontal and parietal regions, as had been hypothesized, although there still seemed to be a continued reliance, although smaller, on the right parietal hemisphere for the harder verbal task. Although bilateral activation was observed at the frontal sites for the hard visuospatial task, this reliance on the right parietal regions was also evident for the harder visuospatial task. The predicted bilateral activation was observed on three of the verbal and three of the visuospatial conditions, with two conditions eliciting strong right hemisphere activation (easy verbal parietal and hard visuospatial parietal). It can therefore be concluded that the hypothesis for bilateral activation at both the easy and hard task levels for the older sedentary group was generally supported.

It was hypothesized that the older active would demonstrate hemispheric asymmetry for the easy tasks and bilateral activation for the hard tasks, similar to the younger groups. However, the older active group demonstrated bilateral activation for both the easy and hard verbal tasks. This observation supports the compensatory view of cognitive aging (Cabeza et al., 2000). While the older active group showed bilateral activation for the frontal sites during the easy visuospatial task, hemispheric asymmetry was clearly observed at the parietal sites, indicating a strong reliance on the right hemisphere, even stronger than that which was observed for the younger groups for this task. This observation supports the overactivation hypothesis recently suggested by Reuter-Lorenz and Cappell (2008). The older active group did show the hypothesized bilateral activation during the hard visuospatial tasks, at both frontal and parietal sites.

In conclusion, some of the hypotheses regarding alpha and the older groups were supported, while others were not. Replications of these observations are necessary before any firm conclusions can be drawn.

Processing Speed, Attention, and Working Memory

Two theoretical frameworks were presented to explain the hypothesized age differences in working memory. Both of these will now be discussed in relation to the findings from this study. Processing speed was measured in an attempt to explain differences in working memory between sedentary and physically active older individuals. Contrary to what was hypothesized, the age effect for processing speed was not mitigated by physical activity. Thus, although processing speed has been shown to be highly correlated with working memory (Kyllonen & Cristal, 1990; Salthouse & Babcock, 1991), this study did not indicate differences in processing speed *or* working memory between the sedentary and active older participants.

Although he has more recently retracted this position, in early research Salthouse (1991, 1996) strongly contended that a generalized decrease in processing speed is responsible for the majority of age-related variance in cognitive tasks. Similar to other studies, the WAIS digit substitution test was used in this study to measure processing speed. As hypothesized, younger individuals were faster at this task than the older participants. It is important to remember that motor speed has been subtracted out via the copying component of this task, so the data rendered do represent pure processing speed, and not differences in writing dexterity that often accompanies aging. Thus, it may be that the younger group's superior performance in the both the verbal and visuospatial working memory tasks are a direct result of faster processing speed. Both the verbal and visuospatial working memory tasks consisted of two parts. First participants had to verify either a sentence or visuospatial equation. Then, the to-be-remembered letter or dot location was presented. If the younger individuals were able to process the verification portion faster, then their entire completion time for the task would be shorter than the older individuals, thereby decreasing the decay of the visual to-be remembered information.

The inhibitory control view emphasizes the role that attention plays in controlling the contents of working memory (Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999, Kensinger, Piguet, Krendl, & Corkin, 2005). The argument is that if an older individual cannot inhibit extraneous information, then the wrong information will be stored and manipulated in working memory, which would impair recall. The present study assessed inhibitory control through the Antisaccade task. In this paradigm, the participant must ignore a distracter letter that appears immediately before the important, to be acted upon, letter appears. In the present study, the younger participants were significantly more accurate in identifying the target letter than the older participants (94.2% vs. 82.6%). It may be that the older participants took longer to pull their attention away from the distracter letter, thus reducing the time for which the target letter was presented. This may have led to more guesswork when it came time to respond, which may also translate into slower reaction times. This idea is supported by the observation that the younger participants were also faster in making their responses (although slower motor skills cannot be ruled out as a plausible explanation for the decreased reaction time in the older groups).

The fact that the older groups showed greater lack of inhibition dovetails nicely with the finding that they also demonstrated lower span performance in the verbal and visuospatial working memory span tasks. The research of Engle (2002) and Kane et al. (2001) clearly draws a relationship between working memory and attention. In their studies, low span participants were significantly slower in identifying letters in the Antisaccade task.

Summary

Overall, many of the study's hypotheses were supported; but, the main tenet of this project, that physical activity would lessen the impact of cognitive aging, was not supported. It was found that age significantly reduced performance on both verbal and visuospatial span tasks, negatively affected n-back accuracy, and increased reaction time. It was also found that task difficulty resulted in an increase in frontal midline theta, indicative of the greater attentional demands of the harder task condition. This effect was accented even more by age for the visuospatial type of task. The present results only somewhat duplicate previous findings of functional lateralization of alpha activity for the younger participants. For the most part, physiological measurements did not match the changes in performance that were observed as task difficulty increased. The anticipated age effect for the physiological data was not evidenced. Predictions regarding age were corroborated by the information processing and inhibitory function data. The younger participants processed information more quickly than the older groups, and information processing speed was correlated with many working memory measurements. Additionally, the younger participants were more adept at inhibitory function than the older groups. However, because the hypothesized age and physical activity interactions were not supported, it is not possible at this time to consider which theory, information processing or the inhibitory function, best explains the proposed relationship between physical activity and cognitive aging.

Strengths, Limitations, and Further Research

It was hoped that the present study would replicate previous behavioral research regarding the effects of age on working memory through the use of behavioral measures of verbal and visuospatial spans, and accuracy and reaction time data for n-back tasks. It was further proposed that the use of EEG data collection would replicate earlier PET studies that suggest differences in alpha and theta between younger and older participants as task difficulty increases. This study proposed building on previous research by introducing physical activity into the cognitive aging model. Although physical activity has been investigated to this end, only a limited number of studies have examined working memory as the construct of interest and few if any have utilized the particular n-back task used in the present investigation.

The forty older individuals who participated in this study were all highly motivated to perform at their best. They listened intently as task instructions were disseminated, they were highly engaged during both practice and experimental trials, and were determined to reach criteria during the practice trials. It seemed as if they were very interested in knowing if their mental capacity was adequate, and their personal pride was on the line. It is possible that the younger participants did not feel this pressure to perform at their maximum capacity. Perhaps this provided a false low record of the younger groups' performance, especially on the harder n-back tasks, thus diluting the age differences for these, tasks, both behaviorally and physiologically.

Another possible limitation of the current study is that classification as sedentary of physically active was based on self-reports. It is probably not likely that a person would classify him- or herself as less active than they actually are. However, it is entirely possible that some individuals, whether intentionally or not, might describe themselves as more active than they really are. Thus, it is possible that, based on this selection/classification method, age x physical activity interactions were not observed because the active group had some false positives, or misclassified, underactive members. Of course, this possibility was considered when this study was being designed. However, the alternatives to self-report were not feasible due to time and financial limitations. The apparatus and skilled technicians necessary to measure aerobic fitness were not available. The other methodological solution, to recruit sedentary participants and engage them in a 6-12 month intervention program was not realistic for the scope of this experiment, such as the research of Kramer et al. (2005). Thus, given these constraints, attempts were made to carefully screen prospective participants for their patterns of physical activity.

Another limitation of this study was that, due to technical difficulties, EEG analyses were run on only fifty-two participants. As this was a mixed between and within subjects design, it would have been preferable to have had more than thirteen participants in each group. It can be argued, however, that physiological data, in general, does not require as large a sample size as behavioral data. However, the rather large standard deviations for most of the theta and alpha data would suggest otherwise. As this experiment was charting new territory, it was rather broad in scope and measured many variables. The paradigm required upwards of three hours to run each participant. It may be that future research should focus on a smaller aspect of this area of study and gather EEG data on a larger number of participants. Perhaps these hypotheses would be better run as a series of experiments, the first of which would be to replicate on several occasions which tasks show significant behavioral *and* physiological age-related differences. Only then would physical activity be entered into the equation, with the ability to measure physical fitness objectively, and not relying on self-report. If and when physical activity is able to be shown as a moderator of the cognitive aging effect, theoretical explanations, such as processing speed and inhibitory function, can be introduced.

Conclusions

Although several key hypotheses for this study were not supported, this still remains a fruitful area of research. Our population of older individuals will continue to rise, as life expectancy increases and the baby boomers reach their golden years. It is imperative that behavioral interventions continue, in hopes of maintaining quality of life well beyond retirement age. Both individuals and society cannot bear the financial burden of managed care for such a large number of persons. Helping older citizens maintain their cognitive processing plays a critical role toward providing them with the choice of continued independent living.

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APPENDIX A

Carpenter Physical Activity Questionnaire

1. Do you engage in leisure-time physical activity (exercise, sports, recreation, or hobbies) that are NOT associated with activities as part of your regular job or household duties?

____YES ____ NO

If you answered NO to question 1, <u>go to question 5</u>. If you answered YES to question 1, continue with question 2.

2. On average, how many days a week do you engage in physical activity? ______

Please read the following definitions in order to answer question 3.

Moderate-intensity physical activity involves an increase in breathing or heart rate, such as walking briskly, mowing the lawn, dancing, swimming, or bicycling on level terrain.

Vigorous-intensity physical activity involves a large increase in breathing or heart rate, such as jogging, high-impact aerobics, swimming, continuous laps, bicycling uphill, carrying more than 25 pounds up a flight of stairs, or standing/walking with more than 50 pounds.

3. Which of the following best describes your pattern of physical activity *over the past year?*

A) ____ 5 or more days a week of moderate-intensity activities (in bouts of at least 10 minutes for a total of at least 30 minutes a day)

B) ____ 3 or more days a week of vigorous-intensity activities (for at least 20-60 minutes per session).

C) ____ neither (please describe) ____
____

4. For how many years have you been engaging in this pattern of physical activity? _________

5. Are you currently employed? _____ YES _____ NO

If yes, do you perform any of the following activities, *for 30 or more minutes a day,* as a regular part of your job? (Check all that apply)

_____ Walking _____ Hauling _____ Lifting _____ Pushing
_____ Carpentry _____ Shoveling _____ Packing boxes

6. How many times per week do you engage in the following transportation physical activities, *for 30 or more minutes a day,* to get yourself to and from places such as work, school, places or worship, and stores?

	Never	1-2/week	3-7/week
Walking	_____	_____	_____
Biking	_____	_____	_____
Wheeling (wheelchair users)	_____	_____	_____

Participants will be classified as "Sedentary" if all of the following criteria are met:

1) Answer NO to question 1
2) Answer NO to question 5, OR answer YES to question 5, but do not check any of the listed activities
3) Answer Never or 1-2/week for items in question 6

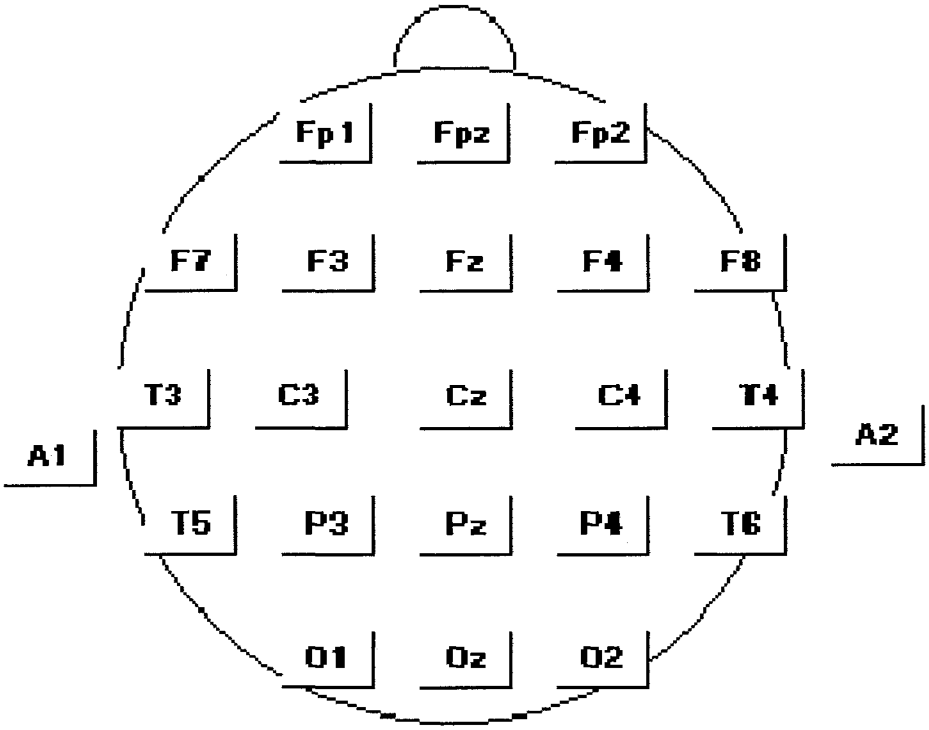
Participants will be classified as "Physically Active" if all of the following criteria are met:

1) Answer YES to question 1 OR if answer NO, answer 3-7/times a week for question 6
2) Answer 3-7 for question 2
3) Answer A or B for question 3

Participants that are not classified as either "Sedentary" or "Physically Active" by the above criteria will be excluded from the study.

APPENDIX B

10/20 ELECTRODE PLACEMENT SYSTEM



APPENDIX C

DEMOGRAPHIC/MEDICAL HISTORY QUESTIONNAIRE

Date _______________
Participant ID# _______

Demographic/Medical History Questionnaire

Answer the following questions accurately and honestly. All information you provide will remain confidential. Please ask the experimenter if you need help understanding any of the questions.

1. What is your age? ______
2. Are you ____male or ______female?
3. What is your ethnicity? ________ African American
   ________ Caucasian
   ________ Hispanic/Latino
   ________ Asian

4. What is the highest level education you have completed?
   ________ Some high school
   ________ Completed high school
   ________ Some college
   ________ Completed college
   ________ Advanced degree (masters, doctorate, MD, lawyer)

5. What is your current occupation?
   ________ student
   ________ retired
   ________ other- please explain ____

6. Do you have a valid driver's license? ____ Yes _____ No

7. Are you active socially? (E.g., Do you visit friends or entertain them at your residence? Do you meet friends for movies, dancing, shopping, meals, coffee, or workouts?)
   ____ Not at all
   ____ Somewhat
   ____ Very much so

Medical History

8. Do you wear corrective lenses (either glasses or contacts) ____ yes _____ no
If yes, do you have them with you today? ___ yes ____ no

9. Are you experiencing any of the following:
_____ color blindness ____ cataracts _____ cataract surgery _____ glaucoma

10. Do you wear a hearing assistance device? ___ yes ____ no
If yes, do you have it with you today? ____ yes ____ no

11. Have you ever been diagnosed with any of the following:

	YES	NO
Coronary heart disease	_____	_____
Congestive heart failure	_____	_____
Stroke	_____	_____
Epilepsy	_____	_____
Traumatic Head Injury	_____	_____
Multiple Schlerosis	_____	_____
High blood pressure	_____	_____
High cholesterol	_____	_____
Diabetes	_____	_____
Emphysema or chronic bronchitis	_____	_____
Osteoarthritis	_____	_____
Cancer	_____	_____
Depression	_____	_____
Thyroid Disease	_____	_____

12. Have you been hospitalized within the last 5 years for a serious illness? ______

13. What is your average alcohol consumption?
_____ none
_____ up to 1 drink/week
_____ 2-6 drinks a week
_____ 1 or more drinks a day

14. Are you a smoker? _____ current _____ past ______ never

15. If you are female, have you ever used hormone replacement therapy?
_____ current _____ past _____ never

If you checked yes, what type of hormone are/were you taking?

____

____

Medication Usage Questionnaire

Please list all medical products that you are currently taking. Include medicinal herbs, vitamins, aspirin, antacid, nasal spray, laxatives, etc., as well as prescription medications (copy names from label, if possible). This information will be completely confidential.

EXAMPLE

Name of Medication: Zarontin

Reason for taking: epilepsy Dosage (each time taken): 500 mg

How often do you take the medication? (circle one)

daily [✓ every other day] weekly as needed

On days that you take the medication, how many times per day do you take it? 3

What time of day do you take the medication? morning, afternoon, evening

How long you have been taking the medication? 5 years

Does this medication cause any problems? makes me sleepy

1. Name of Medication: ____________________

Reason for taking: __________ Dosage (each time taken): ______

How often do you take the medication? (circle one)

daily every other day weekly as needed

On days that you take the medication, how many times per day do you take it? ______

What time of day do you take the medication? ____________________

How long you have been taking medication? ____________________

Does this medication cause any problems? ____________________

____

APPENDIX D

HANDEDNESS QUESTIONNAIRE

Date________________
Participant ID# _______

Handedness Questionnaire

DIRECTIONS. Please indicate below which hand you ordinarily use for each activity. With which hand do you:

1. draw?	1. Right	2. Either	3. Left
2. write?	1. Right	2. Either	3. Left
3. use a bottle opener?	1. Right	2. Either	3. Left
4. throw a snowball to hit a tree?	1. Right	2. Either	3. Left
5. use a hammer?	1. Right	2. Either	3. Left
6. use a toothbrush?	1. Right	2. Either	3. Left
7. use a screwdriver?	1. Right	2. Either	3. Left
8. use an eraser on paper?	1. Right	2. Either	3. Left
9. use a tennis racquet?	1. Right	2. Either	3. Left
10. use scissors?	1. Right	2. Either	3. Left
11. hold a match when striking it?	1. Right	2. Either	3. Left
12. stir a can of paint?	1. Right	2. Either	3. Left
13. on which shoulder do you rest a bat before swinging?	1. Right	2. Either	3. Left

14. Which description best applies to you? (Circle one)

    1. Right-handed and strongly so
    2. Right-handed but only moderately so
    3. Left-handed but only moderately so
    4. Left-handed and strongly so

Score: ________

Chapman, L. J., & Chapman, J. P. (1987). The measurement of handedness. *Brain and Cognition, 6,* 175-183.

APPENDIX E

WAIS-III VOCABULARY STIMULI

1. Bed
2. Ship
3. Penny
4. Winter
5. Breakfast
6. Repair
7. Assemble
8. Yesterday
9. Terminate
10. Consume
11. Sentence
12. Confide
13. Remorse
14. Ponder
15. Compassion
16. Tranquil
17. Sanctuary
18. Designate
19. Reluctant
20. Colony
21. Generate
22. Ballad
23. Pout
24. Plagiarize
25. Diverse
26. Evolve
27. Tangible
28. Fortitude
29. Epic
30. Audacious
31. Ominous
32. Encumber
33. Tirade

APPENDIX F

MINI MENTAL STATE EXAM

The Mini-Mental State Exam

Patient_________________________________ Examiner ___________________________
Date____________

Maximum Score

Orientation

5 ( ) What is the (year) (season) (date) (day) (month)?
5 ( ) Where are we (state) (country) (town) (hospital) (floor)?

Registration

3 ( ) Name 3 objects: 1 second to say each. Then ask the patient all 3 after you have said them. Give 1 point for each correct answer. Then repeat them until he/she learns all 3. Count trials and record.

Trials ___________

Attention and Calculation

5 ( ) Serial 7's. 1 point for each correct answer. Stop after 5 answers. Alternatively spell "world" backward.

Recall

3 ( ) Ask for the 3 objects repeated above. Give 1 point for each correct answer.

Language

2 ( ) Name a pencil and watch.
1 ( ) Repeat the following "No ifs, ands, or buts"
3 ( ) Follow a 3-stage command:
"Take a paper in your hand, fold it in half, and put it on the floor."
1 ( ) Read and obey the following: CLOSE YOUR EYES
1 ( ) Write a sentence.
1 ( ) Copy the design shown.
_____ Total Score

ASSESS level of consciousness along a continuum ____________
Alert Drowsy Stupor Coma

Folstein, M., Folstein, S.E., & McHugh, P.R. (1975). "Mini-Mental State" a practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research,* 12(3); 189-198.

APPENDIX G

GERIATRIC DEPRESSION SCALE

Date _______________
Participant ID# _______

Geriatric Depression Scale (Short Form)

Circle the best answer for how you felt over the past week.

1. Are you basically satisfied with your life?	YES	NO
2. Have you dropped many of your activities and interests?	YES	NO
3. Do you feel that your life is empty?	YES	NO
4. Do you often get bored?	YES	NO
5. Are you in good spirits most of the time?	YES	NO
6. Are you afraid that something bad is going to happen to you?	YES	NO
7. Do you feel happy most of the time?	YES	NO
8. Do you often feel helpless?	YES	NO
9. Do you prefer to stay at home, rather than going out and doing new things?	YES	NO
10. Do you feel you have more problems with memory than most?	YES	NO
11. Do you think it is wonderful to be alive now?	YES	NO
12. Do you feel pretty worthless the way you are now?	YES	NO
13. Do you feel full of energy?	YES	NO
14. Do you feel that your situation is hopeless?	YES	NO
15. Do you think that most people are better off than you?	YES	NO

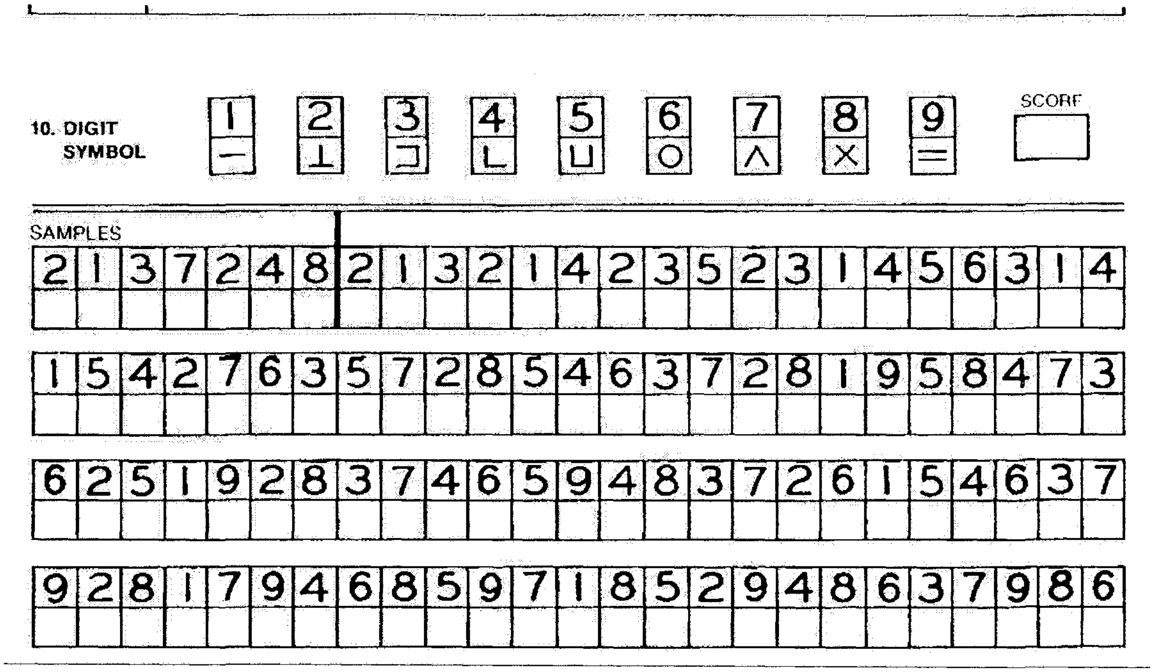
Score: ____________

APPENDIX H

WAIS-III DIGIT SYMBOL CODE AND COPY

Date______________

Participant ID#_______



10. DIGIT SYMBOL

1	2	3	4	5	6	7	8	9
—	⊥	⊐	L	⊔	O	Λ	X	=

SCORE ☐

SAMPLES

2	1	3	7	2	4	8	2	1	3	2	1	4	2	3	5	2	3	1	4	5	6	3	1	4

1	5	4	2	7	6	3	5	7	2	8	5	4	6	3	7	2	8	1	9	5	8	4	7	3

6	2	5	1	9	2	8	3	7	4	6	5	9	4	8	3	7	2	6	1	5	4	6	3	7

9	2	8	1	7	9	4	6	8	5	9	7	1	8	5	2	9	4	8	6	3	7	9	8	6

Date______________
Participant ID#_____

Symbol Copy

Samples

⊥	−	⊐	Λ	⊥	L	X	⊥	−	⊐	⊥	−	L	⊥	⊐	U	⊥	⊐	−	L

⊐	O	⊐	−	L	−	U	L	⊥	Λ	O	⊐	U	Λ	⊥	X	U	L	O	⊐

Λ	⊥	X	−	=	U	X	L	Λ	⊐	O	⊥	U	−	=	⊥	X	⊐	Λ	L

O	U	=	L	X	⊐	Λ	⊥	O	−	U	L	O	⊐	Λ	=	⊥	X	−	Λ

=	L	O	X	U	=	Λ	−	X	U	⊥	=	L	X	O	⊐	Λ	=	X	O

⊥	Λ	⊐	O	U	−	=	X	L	U	Λ	⊐	−	L	X	Λ	=	−	L	U

Λ	−	X	⊥	=	⊐	O	Λ	⊥	X	U	⊥	⊐	−	L	X	L	⊥	Λ	O

Vita

Ellen (Molotsky) Carpenter is the daughter of Irv and Iris Molotsky. She was born in East Northport, New York, and graduated from Walt Whitman High School (Bethesda, Maryland) in 1983. She earned her bachelor's degree from Oberlin College (1987), where she double-majored in Psychology and Physical Education. She received her master's degree in Sport Psychology from the University of North Carolina-Chapel Hill in 1990. Ellen then began a coaching career in cross country/track and field that took her to Central Michigan University (Mt. Pleasant, Michigan), The College of Saint Benedict (St. Joseph, Minnesota), and Old Dominion University (Norfolk, Virginia). In 2001, Ellen returned to graduate school at Old Dominion University, and completed her doctoral degree in Human Factors Psychology in 2008. She began her third year as a full-time lecturer in the Department of Psychology at Old Dominion University in the Fall of 2008.