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Age Related Decline in Memory: Examining the Mediation Effect of Processing, Executive Functioning and Intelligence in Normal Adults

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AGE RELATED DECLINE IN MEMORY: EXAMINING THE MEDIATION EFFECT OF PROCESSING, EXECUTIVE FUNCTIONING AND INTELLIGENCE IN NORMAL ADULTS

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ABSTRACT

Multiple mediation analyses that collectively examine the prominent theories of cognitive aging (i.e., Common Cause, Processing, and Executive Decline Hypotheses) along with other cognitive domains that are sensitive to aging are rare. Moreover, having identified that cognition begins to decline as early as 30 years old, few studies have examined the mechanisms that underlie memory change among younger aging individuals. As a result, it is unclear whether relevant mediating variables have been excluded from early research on age-related memory decline, or to what extent rehabilitative strategies are applicable as early interventions for maintaining cognitive functioning into late life. The present study was designed to examine a multiple mediation model in which processing speed, verbal working memory, executive functioning, visual working memory, and verbal IQ served as potential explanatory variables in the relationship between age and episodic memory among individuals aged 16 to 70 years. Visual and auditory memory outcome variables were examined separately. Both visual and auditory memory proved to be sensitive to aging, but not equally so. In this investigation, auditory and visual memory did not mature symmetrically, as individuals age. The present results showed that memory decline among aging adults was a sensory-specific, functional by-product of the interactive effects of the mediators in the model. Another notable finding was that verbal IQ was found to be the only variable to have a significant indirect effect on the relationship between age and auditory memory, after controlling for the other mediators in the model. For the relationship between age and visual memory, both verbal IQ and visual working memory were found to have significant indirect effects. Verbal IQ emerged as a salient compensatory mechanism underlying age-related memory decline by acting in opposition to commonly discussed mediators, such as processing speed, working memory, and executive functioning. As a result, neither the Processing nor the Executive Decline hypotheses proved significant. In terms of the mediators that stood out, only the mediated effect of verbal IQ was significantly larger than verbal working memory for the auditory memory outcome. The indirect effect of visual working memory was larger than verbal working memory, as well as all other variables in the model except for processing speed. The present study is clinically relevant as it provided evidence for what cognitive factors, when considered together, are most salient targets for cognitive remediation and neuroprotective interventions. Particularly among the middle-aged and older adult population, age may not be associated with such significant declines in memory if visual working memory and verbal IQ can be maintained.

CHAPTER I

Statement of the Problem

Cognitive functioning is essential for actively engaging information presented in daily activities, preserving everyday functioning, and negotiating one's environment. While certain cognitive abilities are relatively unaffected as normal adults grow old, certain areas of functioning decline. For investigators examining normal cognitive aging, memory is the cognitive domain that has garnered the greatest interest for a number of reasons (Zacks, Hacher & Li, 2000). Most notable is that memory impairment is an early hallmark of a number of neurodegenerative conditions that emerge in old age (Hyman & Gomez-Isla, 1996; 1997). Secondly, declines in memory abilities, while corollary with certain neurological illnesses, are common in normal aging. Naturally, with the population of older adults in the United States projected to be approximately 42% of the total population by 2050 (Vincent & Velkoff, 2010), a salient issue for neuropsychologists, geropsychologists, nurses, and rehabilitation specialists is understanding cognitive changes across the adult life span more fully.

A factor influencing the study of cognitive aging is defining what is older and elderly, for which there is no international consensus. In the United States, the chronological age of 65 years is commonly used as a cutoff for "elderly" or "older" persons (Roebuck, 1979). In the United Nations, a cutoff of 60 is loosely used to classify the "older" population, while other countries and sub-societies consider the onset of old age to be anywhere from the fourth to the seventh decade (1979). Various pension, social security and retirement schemes also use age 60 or 65 years for eligibility (1979). Within the gerontology community, researchers have further defined sub-groups of older adults such as the “young old” (60 to 69) or (65 to 74), the “middle old” (70 to 79) or (75 to 84), and the “very old” (80 or 85+) (Forman, Berman, McCabe, Baim, & Wei, 1992; Zizza, Ellison, & Wernette, 2009). For the purposes of the present study, no single classification was adopted; however, the terms “young old” and “older adult” are used to refer to individuals over 60 years old.

The focus of research on age-related memory decline has centered on the older adult population and there has been a proliferation of studies evaluating individuals older than 65 years of age. As a result, there is an underrepresentation of research on cognitive aging across the adult life span and among the young old population. This can likely be attributed to findings that individual cognitive ability becomes stable at approximately twenty-three years of age (Salthouse, 2004a; 2004b); thereby relegating the study of cognitive decline to older samples. Additionally, the considerable controversy within research regarding the age at which cognitive decline begins has made studying cognitive aging among older adults, for whom deficits have already begun to emerge, a more practical approach (Salthouse, 2009). However, there is empirical support that cognition begins to decline as early as the third decade (Daselaar et al., 2007; Park & Payer, 2006), and compared to younger adults, older adults perform more poorly on tasks that measure processing speed, capacity, executive functioning, and episodic memory (Schaie, 1994). These findings from earlier studies reveal the need for research on cognitive change throughout adulthood, particularly for aging individuals under 75 years. The clinical promise of such research is that it will contribute to our understanding of cognitive maturation and ways to maintain abilities over time (Raz, 2005; Reuter-Lorenz et al., 2000). Through an examination of the adult network of cognitive functions along the developmental spectrum, wherein abilities influence and are interdependent on one another, such research will underscore the complexities of cognitive aging and possibly uncover maintenance models for preserving functioning into late life.

To this end, neuropsychology research has shifted toward a more functional approach in understanding the mechanisms through which age related neuroanatomical, neurochemical, and neuropsychological changes are related to specific areas of cognitive decline. Support from early neuroanatomical and neurobiological studies have demonstrated that normal aging is associated with structural changes, including reduction in cerebral gray matter volume, development of white matter plaques and reduction in neural synapses (Bucur et al., 2008). Age related changes in cerebral blood flow and metabolism have also been studied, and findings indicate that the hippocampus, anterior portions of the brain (e.g., prefrontal cortex) and subcortical regions such as the limbic system are most susceptible to metabolic changes and decreases in cerebral blood flow (Lezak, 2004). Such age related changes in the central nervous system often correlate with cognitive and behavioral changes in memory, executive functioning, working memory, and more diffuse cognitive abilities. Furthermore, through brain mapping and neuroimaging studies, neuropsychologists have found these cognitive domains to be supported by the brain areas that are most affected by age. While early research has demonstrated the presence of changes as the human brain ages, what remains to be understood are the overall (i.e., combined) and specific latent effects of certain cognitive abilities on relationship between aging and memory.

A number of neuropsychological theories have discussed and attempted to explain underlying factors that may be responsible for age-related cognitive decline. Discrete cognitive domains have also been studied for their role in indirectly affecting changes in other areas of functioning. From such research, three theories have emerged as the most salient and well supported.

The Common Cause hypothesis posits that sensory functioning significantly predicts intellectual ability and memory for auditory and visual stimuli (Lindenberger & Baltes, 1994), particularly in the aging individual for whom the physiological architecture of the aging brain is changing (Luszcz & Bryan, 1999). Moreover sensory functioning, which includes vision, hearing, grip strength, and tactile recognition, is central to this theory because changes in an individual’s sensory abilities as one ages are believed to mediate the relationship between age and memory. Beyond simple degeneration and brain atrophy, researchers have hypothesized that the integrity of sensory processes is a requisite for cognitive functioning. Therefore, based upon this theory, older adults are believed to have greater memory difficulties than younger individuals because older adults’ sensory acuity is poorer compared to that of younger individuals. Consequently, the integrity of sensory and perceptual processing must be assessed in any neuropsychological evaluation.

In addition, the relationship between aging and cognitive functioning, in particular memory, has been examined with executive functioning serving as a mediator. Executive functions are considered complex processes that are involved in planning, organizing, coordinating, implementing, and evaluating novel activities. The executive decline hypothesis (also referred to as frontal lobe theory) proposes that age-related neurological changes in the frontal lobes serve as the mechanism through which age asserts its influence on other cognitive functions (Luszcz & Bryan, 1999). Areas of higher order functioning subsumed under the construct of executive functioning (i.e., problem-solving, cognitive flexibility, selective attention, error monitoring, decision-making, memory inhibition, and response inhibition) continue to be investigated to determine whether each area represents distinct or analogous concepts, as well as the indirect effect of each area on the age-memory relationship (Testa, Bennett, & Ponsford, 2012).

The cognitive processing model for age-related cognitive decline proposes two mechanisms of mediation including: (1) the rate at which information can be encoded, stored and used and (2) the capacity for tracking and manipulating verbal and spatial information. According to Salthouse (1996), age-related changes in cognitive functioning are significantly influenced by how quickly individuals can think. A number of studies have examined the existence of an indirect effect of processing speed on age-related declines in performance on memory tasks (1996) and fluid intelligence (Salthouse, 2000). Employing structural equation modeling, Hertzog, Dixon, Hultsch, and MacDonald (2003), found that changes in cognitive speed and working memory predicted age-related changes in episodic memory. However, these authors caution against drawing definitive conclusions from their findings due to the methodology employed, which was primarily correlational, involving hierarchical regressions.

Processing capacity, often interchangeably referred to as working memory, is defined as the ability to attend to, temporarily store, and manipulate information. Measured working memory has been one of the most studied topics in cognitive psychology and cognitive neuroscience due to its fundamental role in the performance of both daily activities and cognitively demanding tasks such as remembering a phone number while removing a dish from the oven or mentally solving a computational problem (Wager & Smith, 2003). However, neuropsychology research on working memory as a unique domain is limited due to the conceptualization of working memory, at times, as involving an executive functioning component. This is likely because working memory, like executive functions, is linked to the frontal lobes and it subserves higher order functions (Daselaar, Dennis & Cabeza, 2007).

For the purpose of this study, the operationalization of working memory will be based on two notable working memory models of cognitive aging that are commonly referenced in the literature. The first model purports that age-related changes in memory are indirectly caused by reduced working memory capacity or more specifically decreased resources for manipulating information (Craik, 1986). This reduction in capacity, as one grows older, reduces the individual's ability to manipulate information needed to perform transient, goal-oriented tasks accurately. Ultimately, deficits in working memory lead to disrupted processing of information intended for more long-term storage and retrieval. The second model asserts that as individuals age they become deficient at inhibiting tangential or extraneous information, discarding irrelevant input, and restraining perseverative or inappropriate responses (Hasher & Zacks, 1988). Essentially, this breakdown in complex attention and short-term storage of information within the working memory system does not allow the individual to capture needed information or perform the proper goal directed response. In either model, working memory becomes the suggested link through which age is related to memory.

To date, there are limited multiple mediation analyses collectively examining the different theories of age-related memory changes across the adult life span, particularly among the younger aging population. As a result, it is unclear whether variables not considered in early multiple mediation models would have a significant influence on the age-memory relationship. Moreover, the early multiple mediation models in which all relevant variables are not accounted for have not been fully modeled or explored the complex processes that underlie memory aging, thereby limiting the clinical and rehabilitative promise of such research.

One cognitive factor, for example, that has been excluded from the discussion of memory aging is verbal IQ. In clinical settings, emphasis if often placed on verbal abilities and crystallized intelligence in determining the presence of cognitive decline. Particularly through the use of verbal IQ measures, which are indented to be “hold” or premorbid estimates, neuropsychologists often make comparisons between these and more age sensitive measures (fluid cognition). However, it is interesting to note that many studies examining aging and cognitive change disregard verbal intelligence as a variable of interest. Granted, there is historical evidence that age trajectories for experiential or over- learned knowledge are somewhat stable compared to cognitive abilities that are measured through processing and mental manipulation abilities (e.g., crystallized vs. fluid intelligence). More recently, however, research examining verbal abilities has found that older age and higher education were predictive of higher verbal intelligence (Lentz, 2011). This suggests that verbal intelligence may have a mediating influence on age- related cognitive change and may be relevant as a mechanism by which age influences memory functioning.

Therefore, the purpose of the current cross-sectional study was to contribute to the literature by examining age-related memory change through adulthood as mediated by processing speed, working memory, executive functioning, and verbal IQ. Through

Hayes PROCESS Macros, the following hypotheses were tested:

(I) Cognitive processing speed, verbal working memory, executive functioning, visual working memory, and verbal IQ would mediate the relationship between age and both the auditory and visual episodic memory at the .01 level.

(II) In examining the specific indirect effects it was hypothesized that the specific indirect effect of processing speed on the relationship between age and auditory and visual episodic memory, after controlling for the indirect effect of working memory, executive functioning, visual working memory, and verbal IQ would be statistically significant at the .01 level.

(III) The indirect effect of working memory on the relationship between age and both auditory and visual episodic memory, after controlling for the indirect effect of processing speed, executive functioning, visual working memory, and verbal IQ would be statistically significant at the .01 level

(IV) The specific indirect effect of the executive functioning averaged composite on the relationship between both age and auditory and visual episodic memory, after controlling for the indirect effect of processing speed, working memory, visual working memory, and verbal IQ would be statistically significant at the .01 level.

(V) The specific indirect effect of the visual working memory averaged composite on the relationship between age and auditory and visual episodic memory, controlling for the indirect effect of processing speed, working memory, executive functioning, and verbal IQ would be statistically significant at the .01 level.

(VI) The specific indirect effect of the verbal IQ averaged composite on the relationship between age and both auditory and visual episodic memory, after controlling for the indirect effect of processing speed, verbal working memory, executive functioning, and visual working memory would be statistically significant at the .01 level.

(VII) Contrasting the strength of the proposed mediators against each other in pair wise comparisons, it was purported that the magnitude of the specific indirect effects of processing speed, verbal working memory, visual working memory, executive functioning, and verbal IQ were not of equal size and therefore would be different from each other at the .01 significance level.

To provide context and justification for the present study, the following pages are a review of the relevant literature.

Chapter II

Review of the Literature

A Neuropsychological Model of Memory

Clinical, social, and cognitive psychologists have classified the construct of memory in a variety of ways. The most global classification scheme is short- and long-term memory in which information that is presented briefly for immediate use, is processed by a distinct system, and is rehearsed and stored for later retrieval. However, Tulving (1987), proposed a more sophisticated classification for identifying the various domains of memory. In his multisystem scheme, there are five interlacing systems of memory, which include procedural, perceptual representation, working, semantic, and episodic memory. The present study relied upon this commonly employed memory model in understanding the effects of age on memory.

Briefly, procedural memory is an automatized, over learned system for acquiring behavioral or motor skills such as riding a bicycle. A second system referred to as perceptual representation, or object memory, involves learning to identify items in one’s environment when primed. Working memory, in contrast, involves attending to and manipulating information for later use. Unlike procedural and perceptual memory, working memory involves mental tracking and relies heavily on ones capacity to hold and to manipulate multiple pieces of information. Working memory is a far more complex system of memory than the other types contained within the model. A fourth system, semantic memory, involves learning of general knowledge, while episodic memory, the fifth system, includes learning based upon personal experiences. Both systems rely heavily upon the acquisition of visual or auditory information. However, episodic memory is unique in that it is susceptible to the effects of aging, with declines in episodic memory occurring most commonly among the elderly.

Episodic memory, the system of focus in the present analysis, is supported by neural networking of white matter pathways that connect anterior portions of the brain to the temporal lobes for auditory stimuli and parietal lobes for visual information. Measures of episodic memory can be implicit (cued) or explicit in nature, meaning that they either involve recall (i.e., a reproduction of information from memory) or recognition tasks (i.e., identification of answers from a group of choices). Examiners and researchers most commonly employ clinical measures of learning, such as list learning, for capturing data regarding the functioning of the episodic memory system (Lezak et al., 2006).

Functional magnetic resonance imaging (f-MRI), studies have localized episodic memory in the medial temporal lobe, and have assigned relevance to the prefrontal cortex, particularly for its role in the inhibitory control of distractions. Imaging studies have not only been helpful in localizing memory functions, but have provided a method for linking cerebral aging and changes in brain activity to cognitive aging (Daselaar et al., 2007). In a five-year longitudinal study investigating regional brain volume among healthy adults, significant decreases in volume were found in the caudate, the cerebellum, the hippocampus, and the association cortices (Raz et al., 2005). Decline in the ability to learn, to store, and to retrieve information presented in one's environment, is highly associated with growing old and has emerged as a major health and social issue.

In addition, earlier research comparing memory for auditory versus visual information implicated the medium through which information is presented (i.e., visual, verbal, or both) as a theoretical factor influencing the strength of memory (Baddeley, 1997). Controversy surrounds this topic, particularly whether auditory and visual modalities for memory differ with respect to retention and retrieval of information across the developmental continuum. This is due both to the complexity of encoding and storing information, which includes the ability to convert verbal information into visual representations and to represent visual information with words. Nevertheless, memory for auditory information has been found to be stronger than memory for visual information, which has gained support from studies that have found larger recency and primacy effects of auditory recall tests compared to that of visual tests (Baddeley, 1997). Results from hemispheric asymmetry studies, particularly investigating the medial temporal lobe, remain inconclusive and offer little support for differences in memory for verbal and nonverbal information. However, verbal storage tasks have been associated predominantly with activation of the left-hemisphere near Broca's area, which plays a role in the rehearsal of verbal information through which it is retained short-term. During brief storage of visual spatial information, activation and perfusion occurs predominately in the right hemisphere, and particularly in areas analogous to brain regions that are activated during verbal storage (Jonides et al., 1993). In light of the increasing elderly population, such evidence supporting age related declines in cerebral activity, in the absence of dementia, mild cognitive impairment or other neuropathological syndromes, has sparked concern within the geriatric medicine and neuropsychology communities.

Neurobiological Basis of Age Related Decline in Cognitive Functioning

Changes that occur in the aging brain, including alterations in metabolic, vascular, and neural activity, have been examined for their link to brain-behavior changes across the life span (Ferrer-Caja, Crawford, & Bryan, 2001). Evidence also supports the occurrence of age related changes in cognitive functioning, in conjunction with a reduction in cerebral gray and white matter (Bendlin et al., 2010; see also Giorgio et al., 2010; Westlye et al., 2010). Representing nearly one fifth of the cortex, the frontal lobes have been implicated as an area in which age related neurobiological changes (i.e., the development of senile plaques and reduction in dopamine receptors) predominate. MRI studies have revealed that the frontal lobes show the steepest rate of atrophy. Since the frontal lobes are considered to be heavily responsible for executive functions, this provides support for a link between aging and executive abilities (Crawford, Bryan, Luszcz, Obonsawin, & Stewart, 2000).

The parietal lobes have been found to show steep rates of decline along the adult spectrum. Second only to the frontal lobes, the degradation of the parietal lobes is likely responsible for age related changes in spatial abilities; however, the cognitive correlates of parietal lobe atrophy are not fully understood. Comparatively, volumetric studies of the occipital lobe reveal less noticeable age related atrophy. Subcortically, rates of atrophy vary based on the cortical structure under which the subregion is situated. This means that subcortical structures within the frontal and parietal regions of the brain show greater atrophy than those in other areas of the brain (Dennis & Cabeza, 2008).

In addition, the medial temporal lobes have been widely examined because of their role in consolidation and storage of information into long-term memory. This brain region has received longitudinal and cross-sectional support as an area sensitive to age, which subsequently shows atrophy in middle through late adulthood. As noted above, the subcortical structures that subserve the temporal lobes vary in their rates of atrophy. The hippocampus evidences the highest rates of degradation, with rates of decline increasing between the fifth and seventh decade (Dennis & Cabeza, 2008).

Early research on brain and cognitive aging was respectively divided between the fields of neuroscience and cognitive psychology; however, with the emergence of functional neuroimaging, there has been collaboration between the two fields in drawing associations between brain and cognitive changes. Positron emission tomography (PET) and functioning magnetic resonance imaging (f-MRI) studies have identified age related reductions in glucose metabolism and brain region activation in various portions of the brain. Because a primary source of energy for the brain is glucose, reduced metabolism has a direct impact on the brain cells ability to function optimally. These changes have been considered: (1) markers for diffuse neurophysiological changes, (2) related to age associated brain volume loss, white matter hyperintensities (WMH) changes in cerebral blood flow, and (3) to be correlated with different parameters of cognitive performance including slowed processing and reduced executive abilities (MacLullich, Ferguson, Deary, Starr, & Wardlaw, 2002; Rabbitt et al., 2007).

In addition to structural changes and volumetric studies, PET and f-MRI studies have identified changes in brain regions that are related to decreases in cognitive functions. For example, because of metabolism and activation changes in the left frontal lobe that occur during verbal working memory, this brain region has been found to be relevant in the discussion of normal aging. In addition, the right frontal cortex and the posterior parietal cortex have been similarly linked to spatial working memory (Wager & Smith, 2003). Hypometabolism in the lateral frontal regions of the brain have executive functioning correlates such that reduced glucose metabolisms as one ages can be linked to reduced cognitive flexibility, organization, and complex attention (Wager & Smith, 2003).

Age related changes in cognitive functioning have been further associated with subsequent reduction in the rate and speed of neuronal firing, a theoretical deafferentation of sorts (O'Sullivan et al., 2001). Efficient relay and coordination across neural networks is dependent on the speed at which neural signals are conducted across myelinated axons in the central nervous system. Therefore, white matter disease or damage can cause slowing of cognitive processes, which is frequently seen among individuals who have sustained a traumatic brain injury, because of the disruptions of neural networking (Turken et al., 2008).

Similarly, degradation of white matter pathways, synapses, and connectivity has been increasingly studied among healthy older adults. Simple atrophy or deterioration as a neurobiological mechanism of cognitive deterioration is well supported due to the reliance of episodic memory on white matter pathways that connect anterior portions of the brain to the temporal and parietal lobes. Disruptions of the frontotemporal pathways that occur in advanced age have been hypothesized to be a source of age related episodic memory decline. For example, Metzler-Baddeley and colleagues (2011) examined the age related changes in the microstructure of these tracts. Degradation in the fornix, which is a microstructure traversed by the frontotemporal pathway that is thought to subserve this distinct memory system, resulted in a decline in recall.

Studies examining age related changes in cerebral blood flow (CBF) through single-photon emission computerized tomography (SPECT) have found that there is often a reduction in CBF as one ages. This is relevant because not only have reductions in CBF been linked to volumetric change in the brain and cortical atrophy, but it is believed that blood volume loss in functional tissue instigates decline in the functions respective to the brain region. Extensive vascular and stroke research has been conducted on the structural and functional changes that occur following an ischemic or hemorrhagic event (for a review, see Barnett, Mohr, Sein & Yatsu, 1998). And, the link between changes in blood flow and aging have similar mechanisms including cell loss and tissue damage. The bilateral reductions in regional CBF that are associated with normal aging have been found to occur with greater magnitude in the anterolateral prefrontal cortex, in areas along the lateral sulcus and in the lateral ventricle (Inoue, Mori, Morishima, & Okada, 2005). Findings have been mixed regarding the relationship between CBF, WMH, and atrophy, despite the established importance of cerebral blood supply during WMH development and cerebral atrophy (van Es et al., 2010). However, studies supporting the relationship between CBF, WMH, and atrophy have implicated cerebral blood supply as essential to the quick and uninhibited transmission and storage of information, as well as efficient performance of executive controls (Dennis & Cabeza, 2008). Having established a neurobiological blueprint for age related cognitive decline, neuropsychology research has attempted to clarify what functions are most relevant to understanding, mechanistically, age related changes in memory.

Cognitive Changes along the Adult Life Span

Prior to examining potential mediators of the relationship between age and memory, a discussion about how different cognitive abilities mature throughout adulthood is relevant, particularly due to the interdependence of certain cognitive functions on each other. Often complex, the relationships between measurably distinct cognitive functions are such that compromise or improvement in one area of cognitive functioning can influence other abilities. The field of neuropsychology enriches our understanding of the mechanisms that underlie age related changes in cognitive abilities, and forms a foundation for investigating attributable mediators that have the most salient role in age related cognitive change by understanding the nature of change in the different cognitive functions at different periods along the adult spectrum. Furthermore, appreciating normal cognitive maturation provides the basis for understanding and distinguishing neuropathogenic related cognitive sequelae.

Memory and Aging

A number of researchers have examined age related decline in memory and other cognitive functions (e.g., attention and processing speed) and posit that such changes are a precursor to dementia and another disease processes (Brayne & Calloway 1988; Brayne, 2007; see also Kemper, 1984). Others have reported that such decline is the result of normal changes in the aging brain (Bucar et al., 2008; Thal, Tredici & Braak, 2004). While perspectives on age related memory decline vary, evidence from imaging studies have further revealed age related changes in white matter volume that are linked to changes in ones' ability to store and to retrieve situational and contextual information. After controlling for differences in background factors, Nyberg, Backman, Erngrund, Olofsson, and Nilsson (1996), found age to be a predictor of episodic but not semantic memory performance in non-demented adults. Salthouse, Atkins, and Berish (2003) found significant negative correlations between age and memory, supporting earlier studies that have established this relationship (see Clay et al., 2009; Salthouse, 2001; Salthouse, Fristoe, & Rhee, 1996).

Noack, Lovden, Schmiedk, and Linderberger (2013) found that normal aging affects both spatial and temporal dimensions of episodic memory differently in younger and older adults. Findings further revealed that older adults are particularly impaired at simultaneously processing spatial and temporal context. To compensate, older adults process spatial information at the expense of temporal context. Such compensation often results in memory difficulties for details pertaining to what occurred. Certainly, memory abilities decline with age. What remains to be fully understood is at what ages such abilities begin to decline. Theory and research to date have found that memory shows a steady taper during the third and fourth decade of life with more noticeable memory problems emerging in the sixth, seventh, and eighth decades (Salthouse, 2004b).

IQ and Aging

Lifespan neuropsychology as a field has been instrumental in providing data and models of cognitive development. Traditionally curvilinear in nature, the inverse U-shaped models represented a cognitive peak in early adulthood and accelerated decline when only the adult portion of the lifespan is considered. For IQ however, there has been some debate about the actual developmental trajectory. The first issue that complicates an understanding of the trajectory of IQ is that there are many different types of IQ. Fluid intelligence, for example, is the application of intellectual ability to novel tasks to which there has been no previous exposure and for which efficient completion of the task does not rely on previous learning or automatization (Horn 1978). This means that fluid intelligence is often measured by tasks that involve solving novel problems and non-verbal abstraction. Fluid intelligence, consistent with the curvilinear model, has been purported to decline with aging possibly due to neuronal degeneration - resulting in decreased flexibility and problem-solving abilities that are necessary to meet the demands of novel tasks (1978).

Crystallized intelligence in contrast, has been hypothesized to remain stable or to improve as the individual ages. Of note, vocabulary is one task that has the greatest average correlation with crystallized intelligence (1978). Other tasks correlated with crystallized intelligence include general information and verbal abstraction. Consequently, vocabulary measures are often widely used to represent crystallized intelligence. Previous cross-sectional studies has found support for the fluid and crystallized dimensions of intelligence and have provided evidence for the respective sensitivity and insensitivity of fluid and crystallized IQ to age (for a review, see Kausler, 1991) . However, there is a select body of research indicating that word reading and vocabulary measures to share some association with age.

In a sample of 558 women and 1,163 men between 17 and 102 years of age, individuals were screened for neurodegenerative and neuropsychiatric disease and serially administered tests of immediate visual memory (i.e., Benton Visual Retention Test) and crystallized intelligence (i.e., Wechsler Adult Intelligence Scale Vocabulary subtest) over a 28 year period. Cross sectional and longitudinal analyses were conducted and findings revealed that the period between 65 and 74 years of age years of age was a "watershed for decremental changes" in measures of immediate visual memory and verbal intelligence (Gimbra, Arenberg, Zonderman, Kawas, & Costa, 1995, p. 135). Age was found to account for less variance in vocabulary than in immediate visual memory, which is consistent with earlier research that verbal abilities are more static over time. However, there was evidence that vocabulary increased into the fifth decade, plateaued in early old age (i.e., less than 70 years of age) and showed minimal decline in old-old individuals (i.e., greater than 80 years of age. The most relevant findings from this study came from the longitudinal intraindividual results that tracked changes in memory and verbal IQ for each participant over the course of 13 years. The authors found that the changes in verbal IQ and memory were consistent with cross-sectional differences. Meaning, individuals age 20–39 showed little fluctuation in vocabulary or visual memory. In contrast, during the fourth, fifth, sixth, and seventh decades of life, there were greater cognitive changes with verbal IQ increasing and visual memory decreasing. Consistent with earlier studies, individuals between 65 and 70 were particularly susceptible to cognitive decrements (see also Schaie, 1994).

Elgamal, Roy, and Sharratt (2011) found that older adults have better word reading scores on the National Adult Reading Test (NART) than younger adults. Verhaeghen (2003) also highlighted in his metaanalysis that vocabulary scores among younger and older adults are not insensitive to age. In a review of the interrelationships among visuospatial and verbal working memory processes, the authors found that all process-intensive abilities declined with age while verbal knowledge increased (Park et al., 2002). Taken together, the research suggests that crystallized/verbal IQ has an acquired component, and as an individual matures into adulthood, verbal abilities share a positive linear relationship with age. It has been suggested that in the 8^{th} decade the relationship between age and crystallized IQ changes and abilities subtly decline (Lezak, 2004).

Attention, Working Memory, and Aging

Studies examining working memory along the adult developmental spectrum have consistently found changes in one's ability to manipulate information and divide their attention as individuals age. Working memory capacity is greater in young adulthood, particularly in the context of normal childhood and adolescent development (Park & Payer, 2006). Beginning in the second decade, capacity and processing speed decline, and research has found significant differences between younger (30-50 years) and older adults (65 years and older) in their ability to perform working memory groups (Daselaar et al, 2007). Furthermore, greater task complexity results in larger age differences in working memory (2006, p. 132). This is likely due to the involvement of frontal lobe/executive functions. Research has suggested that visual working memory is more susceptible to aging than auditory working memory, due to the interaction of verbal abilities and knowledge (2006, p. 138). There continues to be a need for research that examines all the nuances of aging as it relates to working memory. However, the literature has clearly established the inverse relationship between aging, attention, and working memory beginning in the third decade of life.

Executive Functioning, Processing Speed, and Aging

The maturation of processing speed and executive functioning along the life span has been well documented (for a review, see Park & Payer, 2006). The early identification of neuroanatomical correlates of executive functioning (e.g., frontal and prefrontal lobes) and processing speed (electrochemical communicating system of axons) have provided the foundation for our understanding of how executive functions and processing speed changes as we age. Essentially, the frontal lobes are the last area of the cortex to develop in early adulthood and given the plasticity of the brain and the continued development of neuronal connections between birth and the second decade of life, it is understandable that these two domains develop and improve between childhood and adolescence. However, at a certain point, the adult brain begins to experience gray matter volume loss, loss of synapses, and reduced neuronal connectivity. Such neurobiological changes, which have been earlier discussed, subserve the age related decline that is often seen in processing speed and executive functions. Studies have shown that after the second decade motor and thinking speed decline (Salthouse, 1991; 1992; 1996; Turken et al., 2008) and that higher order functions such as cognitive flexibility and set shifting degrade (Borosh, 2005; Mejia, Pineda, Alvarez & Ardila, 1998).

Previous Studies of Potential Mediators

As noted above, aging is associated with reduced performance on explicit tasks of episodic memory, such as list recall, paired-associate learning, and story recall. However, the mechanisms that mediate age-related declines in episodic memory continue to grow. By providing evidence for the relationship between age and a number of cognitive functions, previous studies have laid the groundwork for an investigation of the nonpathological mechanisms of these changes.

While the literature on age-related changes in episodic memory has consistently implicated processing speed and executive functioning as mediators, there is also support for the mediating role of age related changes in fluid reasoning and working memory (Salthouse, 1994; Salthouse, Atkins, & Berish, 2003), inhibitory processes and mental tracking (Fabiani & Friedman, 1997; Dumas & Hartman, 2003), and set shifting (Hogan, Kelly, & Craik, 2006). Executive control as a construct with multiple domains has been found to be a significant mediator of the relationship between age and episodic memory

(Ferrer-Caja et al., 2001). The mediating effect of executive functioning on age-related changes in memory is widely accepted. However, often times, executive functioning is examined in isolation, which poses a limitation. Such studies that examine the simple mediation effect of a single factor, in the absence of other relevant mediating factors, have been well documented both for their contribution to the cognitive aging literature, as well as their limited ability to explain the behavior of the mediator in the context of other potentially influential cognitive variables. For instance, Head, Rodrigue, Kennedy, and Raz (2008), conducted a path analysis to examine the mediating role of brain structures, executive functions, and processing speed in age related differences in episodic memory. The authors found that deficits in working memory and inhibition of automatic processes, mediated the relationships between prefrontal volumetric reductions and episodic memory. However, while age differences in performance on set shifting tasks were found, such differences did not mediate the relationship between aging and episodic memory.

Alternatively, reductions in processing speed have been found to explain in part, the relationship between age and episodic memory. Processing speed, as a mediator of the relationship between age and episodic memory, has received substantial empirical support from Hertzog and colleagues (2003), who found that changes in speed and working memory predicted age related changes in episodic memory. Other analyses have identified significant reductions in age associated variance after controlling for processing speed on tasks of verbal fluency, verbal and nonverbal intelligence (Salthouse, Fristoe, & Rhee, 1996), episodic memory (Bryan & Luszcz, 1996; Salthouse, 1995a, 1995b), working memory (Salthouse, 1994), and visuospatial ability (Salthouse, 1991).

Research regarding the mediating effect of processing capacity (i.e., working memory) has shown an indirect effect of working memory on age related memory decline (Salthouse, 1994). Other findings pertaining to the role of working memory and processing speed in episodic memory indicate that these constructs are important for accounting for age related differences (Head et al., 2008; Verhaeghen & Salthouse, 1997). However, the mediating influence of working memory has been consistently found to decrease when the variance accounted for by processing speed is controlled.

Studies of the simple indirect effect of intelligence on the relationship between age and memory are limited. While mechanisms of focus have included processing speed, working memory, and executive functioning, only a select number of mediation studies have been conducted incorporating education, general intellectual ability, and fluid intelligence. Crawford and colleagues (2000), examined the extent to which executive functioning accounted for age-related variance in memory over and above the variance accounted for by general cognitive ability, which was measured by full scale and verbal intelligence indices on the Wechsler Adult Intelligence Scale – Revised (WAIS–R; Wechsler, 1981). Using a series of hierarchical regression analyses, results showed that free recall, recognition, and serial learning were similarly mediated by executive control and general intellectual ability. While modest, executive functioning continued to mediate age-related memory declines when intelligence was controlled for. However, the reverse was not true indicating that executive functions might uniquely influence age related declines in memory.

In a later study, structural equation modeling was used to examine a number of hypotheses, including whether mediators of memory performance had different effects in younger when compared to older adults. These studies found that for younger adults, a negative relationship emerged between performance IQ, memory, and executive function, with executive functioning playing a role in mediating the relationship between age and both Verbal and Performance IQ. Among older adults, executive functioning proved to be a salient mediator, as was general intellectual ability (Ferrer-Caja et al., 2001). These results demonstrate that executive functioning and measured intelligence are in some way associated, and this relationship particularly emerges in mediation analysis that included executive functioning as a mediator.

In a previous study conducted by Bolla-Wilson and Bleeker (1986), verbal intelligence was found to be a significant predictor of performance on every learning trial of the Rey Auditory Verbal Learning Test (RAVLT). In contrast, age and education contributed little to the regression equation. According to the authors, higher verbal intelligence was associated with better learning performance, with women outperforming men. These results suggest that the effects of aging on learning ability are heterogeneous based on verbal intelligence and gender (Bolla-Wilson & Bleeker, 1986). Previous research has further revealed that verbal intelligence/linguistic knowledge serves as a latent variable in the relationship between age and declines in auditory processing (Winfield, 1998). These findings implicate verbal intelligence as a relevant variable influencing the relationship between age and auditory episodic memory. Future investigations are needed to better understand the unique and combined effect of verbal intelligence in visual and verbal memory. The findings from the previously noted studies provide evidence for the role of intelligence as a mechanism for the relationship between age and changes in episodic memory.

CHAPTER III

Method

Data Collection

The present study utilized de-identified archival data provided by the *Normal Neuropsychological Variation in a Normal Population* database, which was being conducted as part of a larger *Driving Study* at Nova Southeastern University's Center for Psychological Studies.

Participants

Examinees were recruited throughout the South Florida area by student clinicians. Participants provided consent to use their data for research purposes. The study included 95 adults between the ages of 16 and 70 years of age, the mean age was 35.63(SD = 16). The sample was found to have a large representation of individuals 21-30 years of age. Approximately 58% of the sample fell between 16 and 30 years of age. Of the sample, approximately 20% fell between 31 and 50 years of age and 22% were between 51 and 70 years of age. However, the distribution of ages within this range was adequately reflective of the 2010 U.S. census data with the greatest portion of the population being between 20 and 40 years old and only approximately 25% of the population being over 55 years old. Forty-eight (50.5%) were males. The sample consisted of Caucasian (66%), Hispanic (12%), African American (18%) and other (4%) ethnicities. Mean level of education was 15.33 years (SD = 2.285) with a range of 10-22 years of education. English was the primary language for all participants.

All volunteers completed a pre-screening questionnaire and intake interview where information regarding the examinees' developmental, medical, psychiatric, familial, social, and legal history was obtained. Volunteers were excluded from the study if they reported any history of cerebrovascular disease, seizure, head injury, serious medical illness, psychiatric illness, and psychopharmacological treatment. Participants, who were unable to make legal and medical decisions for themselves or were not fluent in the English language were similarly excluded from participating in the study.

Measures

Data for the present study was derived from measures administered as part of a larger battery, which assessed measured IQ, memory, attention, executive functioning, academic achievement, emotional functioning, and motor functioning. All instruments utilized in this study were routine neuropsychological and achievement tests frequently employed in the evaluation of an individual's level of neuropsychological functioning. The comprehensive research battery consisted of the following measures:

Wechsler Adult Intelligence Scale – 4th Edition (WAIS-IV). The WAIS-IV consists of subtests designed to tap verbal comprehension, perceptual reasoning, processing speed, working memory and generate an overall intelligence quotient (IQ). Completion of the Vocabulary, Block Design, Matrix Reasoning, Digit Span, Similarities, Information, Symbol Search, Arithmetic, Visual Puzzles and Coding subtests yield scores that represent an individual's estimated verbal comprehension, perceptual reasoning, processing speed, working memory and generate an overall intelligence quotient (Wechsler, 2008).

Wide Range Achievement Test-4th Edition (WRAT-4). The WRAT-4 is a screening instrument used to assess academic progress and achievement level. The test is divided into four sections, which assess word reading, sentence comprehension, spelling, and arithmetic (Wilkinson & Robertson, 2006).

Nelson-Denny Reading Test (NDRT). The NDRT is comprised of reading comprehension and vocabulary sections. The reading comprehension section contains 36 items, which is completed in 20 minutes. A reading rate score measuring the speed of reading can be computed after the first minute. The vocabulary section contains 100 items to be completed in 15 minutes (Brown, Fishco & Hanna, 1993).

Trail Making Test A & B. The Trail Making Test is a measure of visual scanning speed, psychomotor speed, sequencing ability, visual attention, and concentration, and is commonly used as a screening of brain damage. It consists of two parts: Part A and Part B. On Part A, the examinee must first draw lines to connect consecutively numbered circles on a worksheet. On Part B, the examinee has to connect the same number of consecutively numbered and lettered circles on another work sheet by alternating between numbers and letters (Reitan & Wolfson, 1993).

Stroop Color and Word Test. The Stroop Color and Word Test is a measure of executive functioning that consists of three trials. The first trial includes a list of color names that are listed in a random order and printed in black ink. The examinee reads as many words as possible in 45 seconds. The second page consists of a non-meaningful pattern (i.e., XXXX) printed in the same ink colors as the color names of the first page. The examinee names as many colors as possible in 45 seconds. The third page consists of the color names on page one printed in colored ink that does not match the word. The examinee ignores the word and names only the color of the ink in which the word is printed. Again, the examinee is provided 45 seconds to complete the task (Golden, 2003).

Category Test: Computer Version (CAT:CV). This test measures a patient's abstraction or concept formation ability, flexibility in the face of complex and novel problem-solving, and capacity to learn from experience. The task is administered on a computer. Different geometric figures and designs are presented in a pattern on the screen and the examinee is tasked with identifying whether the pattern of figures remind them of a number between one and four. The task is divided into seven subtests. In each subtest, there is one idea, concept or principle that is consistent throughout the entire subtest, which the examinee must figure out. While the examiner is restricted from providing help or cues, the computer provides feedback about whether the individual is right or wrong.

Finger Tapping Test (FTT). The FTT assesses tapping rate. Finger tapping involves three important features: time, spatial amplitude, and frequency. Individuals are asked to tap on a lever using their pointer finger; keeping their other fingers, palm, and arm flat on the table. The task is scored based on the number of taps in a 10-second interval trial averaged across five to ten trials (Reitan & Wolfson, 1993).

Wisconsin Card Sort Test (WCST:CV4). The WCST:CV4 assesses the ability to form abstract concepts and to shift and to maintain cognitive strategies in response to changing environmental contingencies. This test is a measure of executive functioning in that it requires strategic planning, organized searching, goal oriented behavior, and the ability to modulate impulsive responding (Heaton, Chelune, Talley, Kay, & Curtis, 1993).

Wechsler Memory Scale – 4th Edition (WMS-IV). The WMS-IV is a test measuring memory across various modalities, including auditory and visual memory. Additionally, the WMS-IV examines the differences between immediate and delayed memory. Tasks are presented in both recognition and recall formats. This test generates scores measuring an individual's immediate memory, working memory, and delayed memory across auditory and visual modalities. A general memory index is similarly obtained (Wechsler, 2009).

Conners Continuous Performance Task – 2nd Edition (CPT-2). The CPT-2 is a computer-based continuous performance test measuring visual components of attention. The examinee is instructed to respond to a target stimulus by pushing a button and to ignore distracter stimuli (Rosvold & Delgado, 1956).

Minnesota Multiphasic Personality Inventory - 2nd Edition (MMPI-2). The MMPI-2 is a self-report test that assesses personality functioning and psychological disorders. Due to the demands of the task, a 6th grade reading level is required. Instructions are printed on the front of the reusable stimulus booklet. The examinee is instructed to read each statement and to determine whether it applies to him or her. (Butcher, Dahlstrom, Graham, Tellegen, & Kaemmer, 1989).

Composite Variables

To examine the overall and specific indirect effect of processing speed, verbal working memory, visual working memory, executive functioning, and verbal IQ on the relationships between age and auditory and visual episodic memory, a composite variable for each variable was created. Previous mediation research has largely relied on a single measure of a larger construct (e.g., vocabulary subtest for verbal intelligence or Trails B for executive functioning) thereby confining any discussion of their results to that single subtest rather than the non-observable attribute as a whole. Moreover, the present study includes numerous subtests, which were included to examine the dimensions of each cognitive construct under investigation; however, examining the subtests would essentially clutter regression and mediation models. The present study navigates these limitations with its use of the following composite variables.

Episodic Memory

The Wechsler Memory Scale, Fourth edition (WMS-IV) is a comprehensive measure of memory for adults. The instrument contains subtests which measure episodic and visual working memory, both of which are susceptible to age-related decline (Tulving, 1987). The subtest scores provide a number of indices that reflect global memory functioning. Subtests that tap auditory memory assess the ability to freely recall information immediately after an oral presentation and include an immediate and delayed trial for Logical Memory, as well as Verbal Paired Associates. The delayed subtests further capture an individual’s capacity to retrieve orally presented information following a 20- to 30-minute delay. Visual Memory examines the ability to spontaneously recall visually presented information, either immediately following presentation, or following a 20- to 30-minute delay. Administration takes approximately 90 minutes.

Four subtests from the WMS-IV comprise the auditory memory composite. Logical Memory I and II consist of two stories that are presented verbally. Approximately 30 minutes following the immediate presentation of the stories, the individual is asked to recall as much of each of the stories as he or she can remember.

Verbal Paired Associates I and II require that the participant recall word pairs that are orally presented by the examiner. There are four trials of learning and immediate recall in which the examiner primes the participant by providing the first word from each word pair. The individual must respond with the associated word. Following a thirty-minute delay, the examiner presents the first word of each word pair and the participant must recall the associated word from memory. These two subtests measure verbal memory. Internal consistency for the averaged VPA trials has been reported to be .85. Internal consistency for the initial (.74) and delayed (.75) logical memory subtests were found to be high.

Four subtests from the WMS-IV were used to compose the visual memory composite. Visual Reproduction I and II is a measure of visual memory, which requires that the examinee remember and draw figures after being presented with the image for 10 seconds. Twenty to thirty minutes following the initial presentation of the stimulus, the individual is asked to draw the designs from memory. Internal consistency for the initial (.59) and delayed (.46) visual reproduction subtests were found to be moderate.

Finally, in Designs I and II, the participant is presented with 4 to 8 designs on a grid (e.g., one trial with four designs, two trials with six designs, one trial with eight designs). The participant is given cards with designs and asked to place the correct design in the correct location. The items are scored for correct location and correct detail, independent from each another. A bonus is given for a correct design in the correct location (Wechsler, 2009). In the normative sample, obtained internal consistency for Immediate Total ranged from .83 to .90, for Immediate Content ranged from .66 to .88, for Immediate Spatial .70 to .83, for Delayed Total .80 to .90, for Delayed Content .70 to .84, and for Delayed Spatial .67 to .82.

Processing Speed

Processing speed was measured using a composite score derived from the Coding and Symbol Search subtests on the Wechsler Adult Intelligence Scale, Fourth Edition (WAIS-IV; Wechsler, 2008). Administration of the WAIS-IV takes approximately 90 minutes, while the processing speed subtests can be administered in approximately five minutes. Examination of the psychometric properties of the subtests indicate high test re-test reliability (Lezak, 2004; Salthouse, 2005; Wechsler, 2008) and good diagnostic sensitivity, particularly in identifying white matter damage or disease (Turken et al., 2008).

In particular, the Coding subtest is a widely used measure that assesses the ability to complete a series of perceptual, cognitive, and motor operations under time constraints. The Coding subset involves visual and spatial analysis, preservation of symbol-number associations, attention, and motor speed. In the completion of this task, individuals are presented with a key that associates the digits 1 through 9 with different symbols. Examinees are required to go through several rows of boxes that have numbers in the top part but are empty in the bottom part and copy the corresponding symbol underneath each digit. The number of digit-symbol pairs that are correctly completed within a two-minute time limit measures speed of processing. The authors' rationalization for not using age adjusted standard scores was that scaled scores remove, to an extent, the variance accounted for by age from the subtest of focus. The use of raw scores has been supported in the literature (Salthouse, 1996; 2005; Turken et al., 2008). Test-retest reliability for this subtest ranges from .81 to .86.

Symbol Search is a subtest designed to assess information processing speed and visual perception. It is one of two subtests that contribute to the Processing Speed Index (Wechsler, 2008). This subtest is similar to other measures of processing speed (e.g., Symbol Digit Modalities Test, Symbol-Digit Coding, Digit-Symbol Coding) in that high scores require rapid and accurate processing of nonverbal visual information (i.e., symbols without a priori meaning). Each item is presented sequentially in a row. In each row, two symbols are presented to the left, which are the targets. The examinee is asked to identify and to mark with a pencil the symbol that matches the target from four possible answers, or to endorse the “no” box indicating that the target is not present among the answer choices. The examinee is encouraged to respond to as many items as possible within two minutes (Wechsler, 2008). Test-retest reliability for this subtest ranges from .75 to .84.

Working Memory

A composite combining the Digit Span and Arithmetic subtests from the WAIS-IV was computed to measure each participants’ working memory abilities. Of note, both subtests on the WAIS-IV that measure working memory are auditory tasks in which the examinee is asked to attend to, manipulate, and recall information presented verbally.

One of the core subtests of the Working Memory Index of the WAIS-IV, Digit Span, is a verbal working memory task requiring storage, rehearsal, and manipulation of a string of digits presented orally. The length of the stimuli increases as the test progresses. The total raw score is an additive composite of three tasks in which the individual is asked to repeat the string of digits immediately after the examiner, forward, backward or in ascending numerical order (Wechsler, 2008). Internal consistency for the digit span subtest ranges from .89 to .94.

Arithmetic is another core subtest in which the examinee, working within a specified time limit of 30 seconds, is required to mentally solve a series of mathematics word problems. The task involves both computational and auditory short-term memory demands and assesses sequencing ability, numerical reasoning, speed of numerical manipulation, concentration and attention, and distractibility. Internal consistency for the for this subtest ranges from .84 to .91.

Visual Working Memory

A composite combining two subtests from the WMS-IV was computed to measure each participant's visual working memory abilities. Spatial Addition and Symbol Span are subtests on the WMS-IV that measure visual working memory.

The Spatial Addition task was proposed by test developers as an improved measure of mental manipulation of visual information that reduces processing speed and motor demands. For this subtest, the examinee is shown a grid with blue dots, red dots, or both red and blue dots for five seconds. A second grid is then presented for five seconds with additional dots. The examinee is then asked to add the spatial locations of the blue dots, ignore any red dots, and place blue cards in the grid location where only one blue dot appeared and white cards in the grid location where a blue dot appeared in the same location on both pages. Internal consistency for this subtest ranges from .89 to .93 and test retest reliability was .77. Spatial Addition is a highly reliable measure (Wechsler, 2009).

Symbol Span, another subtest on the WMS-IV, was developed as a visual analog to Digit Span. The reliability of the subtest ranges from .85 to .89 (Wechsler, 2009). Symbols are presented on a page, and the examinee is required to visualize rather than to process verbally from their left to right. The stimulus is presented for five seconds and then the examinee must choose correct designs in the correct order. The length of the symbol string increases as the test progresses; however, there is a forward condition only. Internal consistency for the Symbol Span subtests ranges from .76 to .92 with test retest reliability being .72 (Wechsler, 2009). As both subtests that comprise this composite are verbal in nature, the composite will be referred to as “verbal” working memory.

Executive Functioning

Executive functioning was measured using a composite average calculated from scores on the Trail Making B test, the Category test (CAT) and the Wisconsin Card Sorting test (WCST; Heaton, Miller, Taylor, & Grant, 2004). Each of these tests have been found to load on executive functioning factor; however, the tests have also been shown to measure various sub-domains of executive functioning. For example, in regression analyses examining what best predicts Trails B performance, cognitive flexibility (i.e., percentage of perseverative errors on the WCST) was found to be most significant. Trails B performance has also been found to be highly corrected with other set-shifting tasks (Straus, Sherman, & Spreen, 2006, p. 668). Exploratory factor analyses have found evidence that the WCST loads on three factors including, “ability to shift set, problem solving/hypothesis testing, and response maintenance” (2006, p. 535). Factor analysis of the CAT indicated that the seven subtests load on two factors reflecting spatial analytic skills (i.e., spatial positioning and proportional reasoning factors) (2006, p. 433).

The Trail Making B test is a measure of visual scanning speed, psychomotor speed, sequencing ability, visual attention, concentration and cognitive flexibility. Trails B consists of a page with letters and number arranged randomly on the page, encased in small circles. Examinees are asked to draw a line between the numbers and letters sequentially, alternating between a number and a letter as quickly as they can. The total amount of time required to complete Trails B is used to measure executive functioning (Reitan & Wolfson, 1993). Administration takes approximately 5 minutes. With respect to its reliability and validity, TMT-B has been found to be significantly correlated with other measures of executive functioning including the Stroop Color Word Test (.55), Controlled Oral Word Association Test (COWAT) (.38) and the WCST percent perseverative errors (.34) (Chaytor, Schmitter-Edgecombe, & Burr, 2006).

The CAT was used to measure non-verbal concept formation and the ability to shift and to maintain problem-solving strategies. The test was administered on the computer. In a standard administration, the client is prompted to stop and to wait for the examiner to offer additional instructions to complete each subtest. After the instructions have been read, the examiner must press the word "enter" on the computer keyboard in order for the administration to continue. Administration takes approximately 30 minutes (Reitan & Wolfson, 1993). Internal consistency for the subtests 3-7 were found to be high (.77–.95).

The Wisconsin Card Sorting Test, computer version (WCST:CV4) assesses the ability to form abstract concepts and to shift and to maintain cognitive strategies in response to changing environmental contingencies. This test is considered a measure of executive functioning in that it requires strategic planning, organized searching, goal-oriented behavior, and the ability to modulate impulsive responding. During this computer task, individuals are asked to match a key card with one of four fixed cards. The 128-card deck contains cards that have the shape of either a star, cross, triangle or circle. Any given card can have either one, two, three, or four matching shapes in either red, yellow, green or blue. The examiner is limited in the feedback and the instruction he or she may offer regarding how to match each card; however, the examinee is prompted by the computer program when they give a correct or incorrect response. Administration takes approximately 15 minutes. Interscorer and intrascorer reliability have been found to be high (.83) for this subtest.

Verbal Intelligence

A composite score derived from the subtests that comprise the Verbal Comprehension Index (VCI) of the WAIS-IV was utilized to measure verbal intelligence. The Vocabulary subtest on the WAIS-IV (Wechsler, 2008) is a measure of expressive verbal abilities. The examinee is presented words both orally and visually and asked to provide a definition. Performance on this task is considered the most robust measure of pre-morbid cognitive ability (Lezak, 2005). Furthermore, the Vocabulary subtest correlates highly with the Verbal Comprehension Index and coefficients ranged from .93-.96.

The Similarities subtest measures logical thinking, verbal concept formation, and verbal abstract reasoning. Two objects or concepts are presented, and the examinee is asked to tell how they are alike. The task is untimed. Internal consistency for this subtest ranges from .81 to .91. The Information subtest measures general fund of knowledge and it is frequently employed in research as a measure of verbal intellectual ability. This subtest measures general cultural knowledge, long-term memory, and acquired facts. Individuals are asked questions about different topics such as geography, science, and historical figures. The questions encompass a wide range of knowledge typically acquired during ones primary and secondary education. Internal consistency for this subtest ranges from .89 to .96.

In creating the composite variables, raw scores were first re-standardized into non-age-corrected z-scores. The rationalization for not using age adjusted standard scores provided by the Wechsler or Heaton normative tables was that such scores remove, to an extent, the variance accounted for by age from the variable of focus. While the use of raw scores has been supported by previous studies examining age related cognitive decline (Salthouse, 1996; 2005; Turken et al., 2008), and recommended when neither comparisons nor interpretations are drawn between the participants performance on the different measures (Rucker, Preacher, Tormala, & Petty, 2011), raw scores have serious limitations. Furthermore, using composite variables reduced the number of mediator variables included in the mediation model.

The established categorization of subtests into cognitive domains (Lezak et al., 2004) was considered when constructing the composites thereby ensuring that the individual subsets within each composite were significantly correlated. Essentially, the subtests that were used to comprise the latent composite variable have been previously incorporated together into an index/composite score such as the WAIS-IV or WMS-IV indices (Wechsler, 2008) or have been found to load on a executive ability factor (Strauss, Sherman, & Spreen, 2006, p. 432).

Norms for the Category Test and Trails B were provided in the *Revised Comprehensive Norms for an Expanded Halstead-Reitan Battery: Demographically Adjusted Neuropsychological Norms for African American and Caucasian Adults* (Heaton et al., 2004, p. 88). Normative data for the immediate and delayed subtests on the WMS-IV were accessed for the 25-29 age group from the *WMS-IV Technical and Interpretive Manual* (Wechsler, 2009, p. 129). For subtests on the WAIS-IV, reference group norms were provided in the *WAIS-IV Administration and Scoring Manual* (Wechsler, 2008, p. 219). While the standardization data (i.e., raw means and standard deviations) for the

WCST normative sample 20-29 age group were provided in the *WCST Manual Revised and Expanded* (Heaton et al., 1993, p. 25), these data were not available for the WAIS-IV, WMS-IV, or Halstead-Reitan subtests.

Therefore, using a methodology adapted from Ardila (2007), raw means and standard deviations were deduced for each WAIS-IV, WMS-IV, and Halstead-Reitan Battery subtest.

(1) For each subtest, the raw scores corresponding to the scaled score 10 were considered the mean. When the scaled score of 10 corresponded to a raw score range (e.g., 21-24), the mean for the range was used (e.g., 22.5).

(2) For calculating the standard deviations, scaled scores equal to seven and 13 (i.e., plus and minus one standard deviation from the mean) were selected. When the scaled scores of seven and 13 corresponded to a raw score range (e.g., 21–24) the raw score range was averaged (e.g., 22.5). The raw mean was subtracted from the raw score corresponding to a scaled score of seven, and the raw mean was subtracted from the raw score corresponding to a scaled score of 13. Next, the two differences were added and divided by two. The resulting value was considered the standard deviation for that particular subtest.

(3) Next using Statistical Package for the Social Sciences (SPSS), subtest raw scores were transformed into z-scores by subtracting the mean from each individual's raw score and then dividing by the computed standard deviation.

(4) To create composite variables, an individual's z-scores for the respective subtests that contribute to the composite were averaged together to reflect their abilities within the cognitive domain measured by the composite (e.g., Category test, Trails B, and

WCST form Executive Functioning composite).

Procedure

The present study utilized archival data collected as part of a larger study. As part of the original data collection, participants were screened to determine their eligibility for inclusion in the study. Exclusion criteria include a history of cerebrovascular disease, head injury, serious medical illness, psychiatric illness, and both psychological and psychiatric treatment. All participants reviewed and signed a consent form indicating that they understood and agreed to the procedures, risks, and benefits of participating in the study and their right to confidentiality was discussed. Next, volunteers completed a demographics questionnaire which included questions to obtain information regarding age, education, gender, ethnic group, driving frequency, and accidents. Completion of the demographics questionnaire took approximately five minutes.

Under the supervision of a licensed psychologist, psychology trainees administered a neuropsychological battery that consisted of measures of intelligence, memory, executive functioning, processing speed, attention, motor functioning, visual spatial abilities, and emotional functioning. All instruments utilized in this study were psychological and achievement tests frequently utilized in the evaluation of neuropsychological functioning. In total, testing took approximately 18 hours, which was broken into multiple three-hour test session blocks. Following completion of the evaluation, findings regarding performance were discussed with and approved by the licensed psychologist. A report summarizing the results was provided to each participant once testing was concluded. Data were input into the SPSS, Version 18.0. Files were de-identified to ensure that confidentiality was maintained.

Institutional review board requirements

Prior to conducting data analysis for this archival study, approval was obtained from the Institutional Review Board (IRB) at Nova Southeastern University (File Number StewartJ.2).

CHAPTER IV

Results

Preliminary Analysis

To examine the total and specific indirect effect of processing speed, verbal working memory, executive functioning, visual working memory, and verbal IQ on age-related decline in both auditory and visual episodic memory, a composite variable was created for each proposed mediator and outcome variable in the study. This included transforming the raw scores for each subtest under study into a z-score, the methodology for which was adapted from previous studies (Cohen, 1990; see also Ackerman & Cianciolo, 2000; Anderson, Kunin-Batson, Perkins, & Baker, 2008;) and has been discussed in detail in the previous chapter. Once the subtests raw scores were converted into z-scores, respective subtests were averaged together into a composite that represents each proposed mediator and outcome variable under study.

Preliminary analyses were conducted to examine the descriptive statistics and distribution of scores for each composite variable and the respective subtests that contribute to each composite. Table 1 summarizes the descriptive statistics and distribution of z-scores for each subtest and composite variable. The distribution of scores for the verbal IQ, processing speed, working memory, auditory memory, and visual memory composites were approximately symmetrical, while the distribution of scores for the visual working memory composite were mildly negatively skewed. The executive functioning composite was moderately-to-highly, negatively skewed, indicating that the mean performance of the present sample on tasks of executive functioning was higher than what is seen in a normal population, and that fewer individuals in the present sample did poorly on the task. In the preliminary examination of kurtosis, distributions for the executive functioning composite were highly concentrated around the mean and possessed lower variance with a lower number of scores out in the tails of the distribution.

Table 1
Descriptive Statistic for Neuropsychological Composite Data

	Mean	Range	SD	Skewness	Kurtosis
Verbal IQ Average	.7972	2.86	.591	-.209	-.572
Similarities	.7860	3.24	.712	-.330	-.568
Vocabulary	.803	2.70	.632	-.138	-.603
Information	.802	3.40	.818	-.112	-.695
Processing Speed Average	.091	3.77	.779	-.274	-.154
Symbol Search	.063	4.12	.900	-.087	-.216
Coding	.119	3.89	.800	-.306	.071
Working Memory Average	.347	3.46	.659	-.181	.289
Digit Span	.313	4.17	.820	-.207	-.223
Arithmetic	.381	3.50	.736	-.119	-.240
Visual Working Mem. Average	.238	3.96	.808	-.540	.247
Spatial Addition	.145	3.79	.903	-.629	-.399
Symbol Span	.331	4.53	.901	-.428	.441
Executive Functioning Average	.146	3.12	.589	-1.988	4.624
Category	-.1194	4.24	.959	-1.213	.956
WCST	.231	2.99	.586	-1.944	4.343
Trails B	.326	4.32	.615	-2.105	7.187
Auditory Memory Average	.542	2.45	.583	-.261	-.515
Logical Memory I	.828	3.59	.793	.059	-.595
Logical Memory II	.466	3.11	.682	.083	-.673
VPA I	.387	3.09	.848	-.296	-1.121
VPA II	.487	2.33	.627	-1.165	.424
Visual Memory Average	.251	3.72	.886	-.427	-.535
Visual Rep I	.262	4.25	1.040	-.254	-.478
Visual Rep II	.476	4.57	1.083	.100	-.580
Designs I	-.050	4.24	1.098	-1.033	.252
Designs II	.316	3.33	.897	-.607	-.566

Note. SD is Standard Deviation. Means represent averages of z-scores.

The distribution of scores for all other mediating and outcome variables indicated less concentration of data around the mean and were symmetrical. Results were interpreted using cut-offs established by Bulmer (1979).

The means for each re-standardized z-score composite and respective subtests fell above the mean of a z-score (i.e., greater than 0); indicating that the present sample is higher functioning than the samples used to generate normative data for each subtest. This is likely attributable to the present sample being largely drawn from graduate level students and professionals within the South Florida community, and the average education level being 15.33 years (*SD*= 2.285). Consequently, consideration was given regarding the extent to which the findings from this study are generalizable to the lower education groups within the general population.

Next, the correlations between age, the four proposed mediators, and the two dependent variables were examined in order to determine whether the present data would support previous studies that have found a relationship between age and changes in cognitive abilities. Table 2 contains the correlation coefficients between the predictor variable and each of the proposed mediator and outcome variables.

Age was negatively associated with processing speed, visual working memory (i.e. visual processing capacity), executive functioning, auditory memory, and visual memory. Verbal IQ increased in a linear fashion as age increased, which is inconsistent with previous literature establishing that performance on verbal IQ measures remains stable in adulthood; declining with age most noticeably after 80 years old (Park et al., 2002). There was no association between age and working memory.

While there were a large number of significant correlations between the proposed mediator and outcome variables, the correlation coefficients between visual working memory and executive functioning $r(95) = 0.722$, $p < .001$, as well as visual working memory and visual memory $r(95) = 0.767$, $p < .001$, were significantly high. To address concerns of shared variance, the multiple mediator model was run excluding executive functioning and then excluding visual working memory. Notably, the total and specific indirect effects for the auditory memory outcome did not change significantly. In addition, the results for the visual memory model suggested that executive functioning and visual working memory accounted for separate variance and when excluded significantly reduced the amount of variance accounted for by the overall mediator model.

Table 2
Correlations between the Independent, Mediator and Outcome Variables (n = 95)

Composite Variables	1	2	3	4	5	6	7
1. Age	-						
2. Verbal IQ	.263**	-					
3. Processing Speed	-.523**	-.001	-				
4. Working Memory	-.158	.394**	.423**	-			
5. Visual Working Mem.	-.624**	.130	.604**	.443**	-		
6. Executive Functioning	-.558**	.209	.564**	.420**	.722**	-	
7. Auditory Memory	-.397**	.247	.301**	.387**	.466**	.443**	-
8. Visual Memory	-.642**	.171	.576**	.350**	.767**	.629**	.514**

Note. ** Correlation is significant at the .01 level (2-tailed).

Furthermore, an a priori examination of multicollinearity was performed. After running a multiple regression analysis in which age, processing speed, verbal IQ, working memory, visual working memory and executive functioning were included as predictors, the variance inflation factor (VIF) results were reviewed and are summarized in Table 3. Results were considered significant and indicative of multicollinearity if the VIF, which is the amount of inflation in the variance accounted for by a variable due to its linear dependence on other predictors, was greater than or equal to five (Hair, Anderson, Tatham & Black, 1995).

Table 3
Multiple Regression Test of Multicollinearity

Model	VIF
Age	1.270
Processing Speed	1.820
Verbal IQ	1.574
Working Memory	2.432
Visual Working Mem.	2.303
Executive Functioning	1.270

The VIF was found to be less than five and therefore considered within limits to rule out significant multicollinearity (Pallant, 2007). With a clearer understanding about the shape of the data, as well as the behavior of the of the mediator and outcome variables when correlated with each other, a bootstrap analysis was performed looking at the behavior of these variables within a multiple mediation model.

Total Indirect Effect

Hypothesis I

First under investigation was the hypothesis that cognitive processing speed, verbal working memory, executive functioning, visual working memory, and verbal IQ would mediate the relationship between age and both the auditory and visual episodic memory at the .01 level. Figures 1a and 1b represent conceptual models of this hypothesis.

Figure 1a
Illustration of the hypothesized multiple mediation model for Auditory Memory

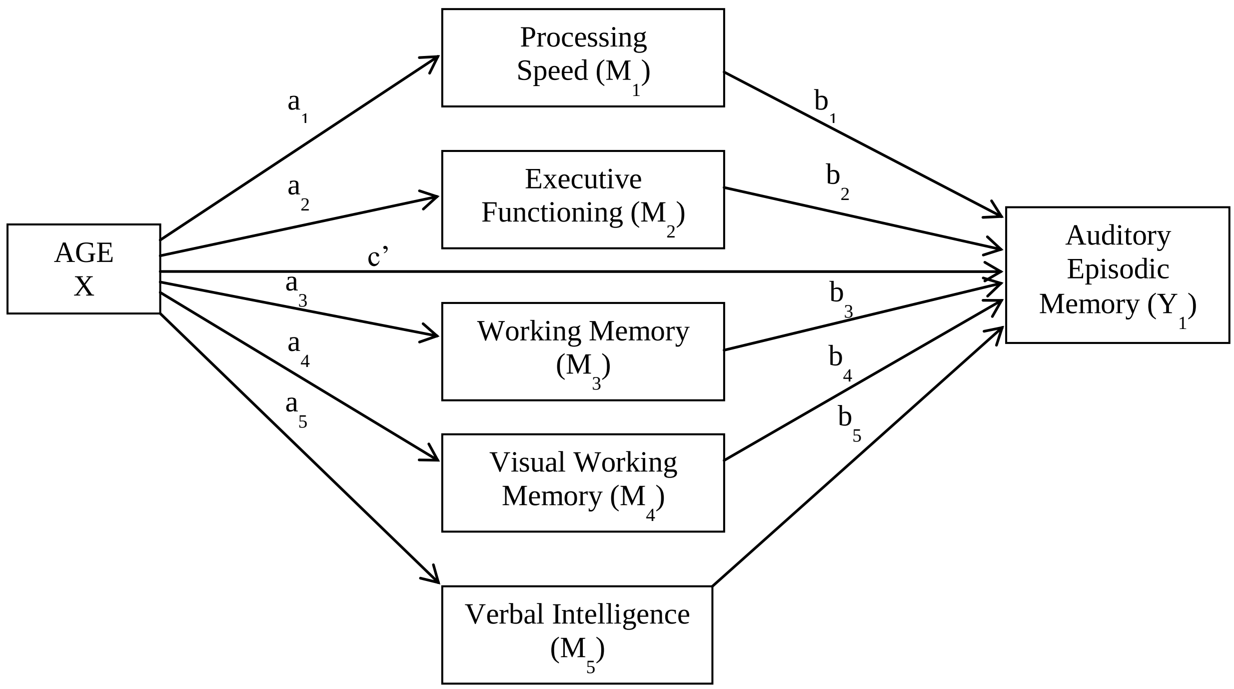
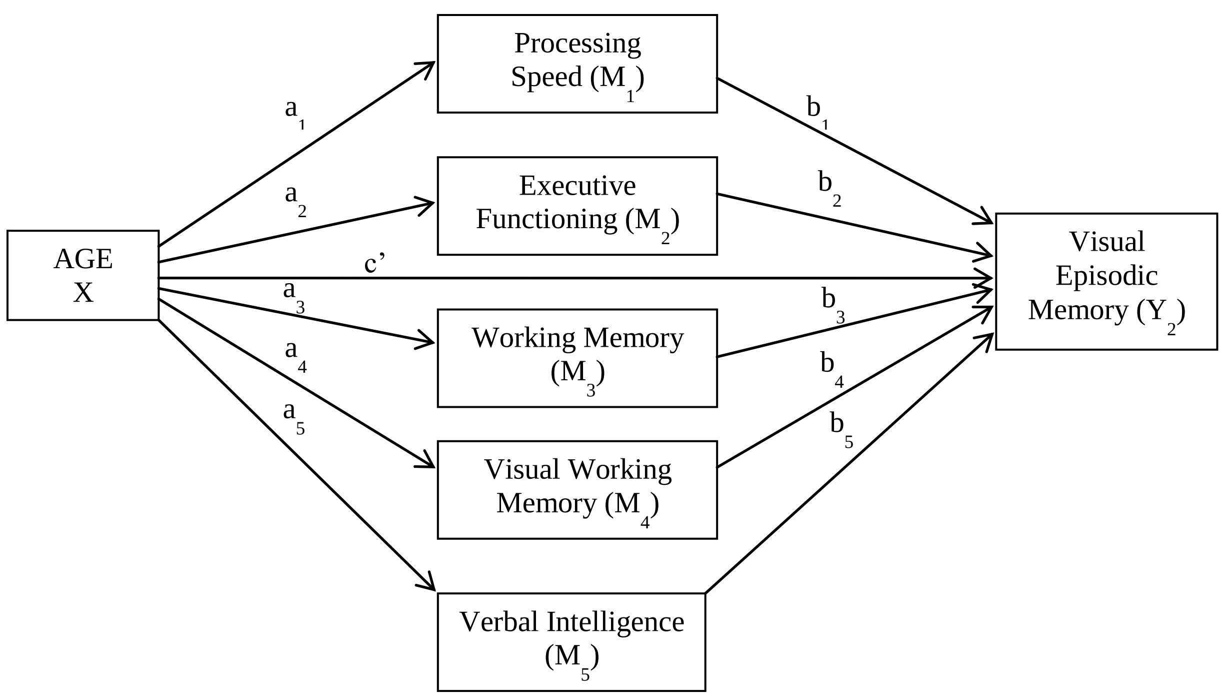


Figure 1b
Illustration of the hypothesized multiple mediation model for Visual Memory



While multiple mediation has traditionally been assessed using two approaches referred to as the Causal Steps Approach (Baron & Kenny, 1986) and the Product of Coefficients approach (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002), the author employed a bootstrap statistical method (Preacher & Hayes, 2008) using 5,000 samples with replacement for the present study.

In the Causal Steps Approach, a series of simple or multiple regression analyses are run. For the first step, the regression equation tests whether the independent variable predicts the dependent variable. The unstandardized regression coefficient represents the effect of X on Y (e.g., *c* path or total effect), and is expected to be significant at the .05 level. The second step assesses whether the independent variable predicts the mediators.

The unstandardized regression coefficient in this model represents the relationship of the independent variable with the mediator or the *a*-path, and is expected to be significant at the .05 level indicating that the independent variable is related to the mediators after controlling for the other mediators. In multiple mediation, this step is repeated for each proposed mediator variable. For the third step, all mediator variables are included as predictors of the dependent variable, and the independent variable is controlled for. Regression coefficients representing the extent to which each mediator predicts the dependent variable (*b* path), after controlling for the other predictors in the model, are provided. If both the *a* and *b* paths are significant, it is believed that there is a significant indirect effect, and the indirect effect is essentially, represented by the product of the *a* and *b* paths. Lastly, to determine if full mediation has occurred, the regression coefficient for the relationship between the independent and dependent variable must be non-significant, having controlled for the mediators variables. This is known as the *c’* path or direct effect.

Similarly, the product of coefficients approach requires that two regression analyses be conducted where the product of the two regression coefficients would represent the indirect effect. Next, the standard error of this indirect effect must be calculated using a formula, the most common of which is the Sobel test. Dividing the indirect effect by its standard error creates a Z-score distribution, which if greater than 1.96 or less than -1.96, indicates the presence of a significant total indirect effect.

However, both of these earlier methods are limited in that they assume multivariate normality, or more specifically that the indirect effects and standard errors generated from the series of regressions conducted will be normally distributed. This assumption is difficult to meet and is often violated, particularly in studies with economic constraints such as smaller samples sizes and low budget. Furthermore, the product of coefficients approach has very low power.

Bootstrapping, a nonparametric re-sampling procedure, is a widely utilized method for testing simple and multiple mediation in the behavioral sciences. Initial examinations of bootstrapping have determined that its performance is superior to other methods including the Sobel test or Baron and Kenny's causal steps approach, in that bootstrapping has higher power and lower Type I error (Preacher & Hayes, 2008). Furthermore, this statistical method for testing multiple mediation is recommended for small to medium sized samples, because it adjusts the sampling distribution of the mediated effects when the distribution of scores is skewed away from zero.

Bootstrapping is the process of calculating the effect of the independent variable on the dependent variable through the mediator(s), which is represented as the computed product of the coefficients for the *a* and *b* paths or indirect effect (*ab*). When run in SPSS for a given data set, bootstrapping treats the sample as if it was the population data and randomly draws a select number of cases to compute the indirect effect, replacing those cases and drawing another random sample for which the indirect effect is calculated. Using replacement, 5000 separate samples are drawn at random and the indirect effects are calculated. Next, upper and lower confidence limits are established signifying either 95% or 99% confidence that the true indirect effect lies within this range. If the established confidence interval does not include zero, then the indirect effect differs significantly from zero, suggesting mediation has occurred. Hayes' PROCESS Macros was run (Hayes, 2013). The output provides the coefficients, standard error and *t* statistic for the *a, b, c*, and *c'* paths, as well as confidence intervals for the total indirect effect and the specific indirect effect of each mediator controlling for the other mediators in the model. The multiple mediation output provides effect sizes for both the direct and indirect effects including, the *Ratio of the Indirect to Total Effect* (Sobel, 1982); the *Ratio of the Indirect to the Direct Effect* (Alwin & Hauser, 1975); the *Partially Standardized Indirect Effect* (MacKinnon, 2008, p. 85); and the *Completely Standardized Indirect Effect* (Cheung, 2009; Preacher & Hayes, 2008b). Finally, pairwise contrasts between all the specific indirect effects are calculated by dividing the difference of the indirect effects by the standard error and deriving a 99% confidence interval. Results are considered significant if the established confidence interval does not include zero.

The present multiple mediation model, which was conducted to examine the effect of age on auditory and visual episodic memory via the total and specific paths of the proposed mediators, contained the five averaged composite variables that represent the five mediators under study (i.e., processing speed, working memory, executive functioning, visual working, and verbal IQ). The model was run for the auditory memory and visual memory outcome. Point estimates of the indirect effect were considered significant when zero was not included within the lower and upper limit of the 99% bias corrected confidence interval. Results from the overall model examining age related change in auditory memory are summarized in Table 4.

Table 4
Summary of mediation results (5000 bootstrap samples)

IV	M	DV	Effect of IV on M (*a*)	Effect of M on DV (*b*)	Indirect Effect (*ab*)	Total Indirect Effects	Direct effects (*c'*)	Total effects (*c*)
				Model 1				
Age	PS	AM	-.026**	-.061	.002	-.002	-.013**	-.015**
Age	EF	AM	-.021**	.069	-.001	-	-	-
Age	WM	AM	-.007	.164	-.001	-	-	-
Age	VWM	AM	-.032**	.096	-.003	-	-	-
Age	VIQ	AM	.010**	.231**	.002**	-	-	-
				Model 2				
Age	PS	VM	-.026**	.156	-.004	-.016**	-.019**	-.036**
Age	EF	VM	-.021**	-.003	.000	-	-	-
Age	WM	VM	-.007	-.077	.001	-	-	-
Age	VWM	VM	-.032**	.507**	-.016**	-	-	-
Age	VIQ	VM	.010**	.338**	.003**	-	-	-

Note. Independent Variable (IV), Mediating Variable (MV), Dependent Variable (DV), Processing Speed (PS), Executive Functioning (EF), Working Memory (WM), Visual Working Memory (VWM), Verbal IQ (VIQ) , Auditory Memory (AM), and Visual Memory (VM).
**Significant point estimate ($p < 0.01$)

The findings were consistent with past studies establishing the relationship between age and the proposed mediators (i.e., "*a*" paths). Processing speed, after controlling for working memory, visual working memory, executive functioning, and verbal IQ was significantly related to age. This was also true for visual working memory, executive functioning, and verbal IQ composite; however, age was not significantly related to the working memory composite.

For auditory memory, there was a significant total effect of age when the mediators were not included in the model (i.e., "*c*" path). That effect was reduced when the five mediating variables were involved, but remained statistically significant at the .01 level. Findings from the analysis further revealed that the total indirect effect of age on auditory memory through all five proposed mediators (i.e., *ab* paths), was non-significant, as zero was contained within the upper and lower limit of the 99% confidence interval for the total indirect effect. Therefore when taken together, processing speed, working memory, visual working memory, executive functioning, and verbal IQ did not mediate the relationship between age and decline in auditory memory.

Note however, that in this model the specific indirect effect for processing speed (ab = .002) and verbal IQ (ab = .002) when compared to the direct effect (c' = -.013), as well as the indirect effects for the other mediators, have opposites signs. This pattern of coefficients indicates the presence of inconsistent mediation where the indirect effects of processing speed and verbal IQ are working in the opposite direction of the other mediators. Whereas increasing age is associated with declines in visual working memory executive functioning, and processing speed, which is expected to impair performance on auditory memory tasks, in this model processing speed is associated with better auditory memory performance. Furthermore, increased age was found to be associated with higher verbal IQ and enhanced performance on auditory memory, which essentially competed against the indirect effects of the other mediators in the model. This phenomenon is known as suppression. Conger (1974, p. 36–37) defined a suppressor variable as, “a variable which increases the predictive validity of another variable (or set of variables) by its inclusion in a regression equation.” In an examination where the magnitude of the regression coefficient represents predictive validity, suppression would be present if the magnitude of the relationship between an independent variable and a dependent variable became larger with the addition of a third or latent variable (MacKinnon, Krull, & Lockwood, 2000).

To confirm that suppression was occurring, a simple mediation bootstrap including age as the predictor variable, auditory memory as the outcome and verbal IQ as the single mediator was run. The results confirmed that including verbal IQ in the model increased the indirect effect of age on the outcome where the total effect ($c = -.015$, $SE = .004$) was closer to zero than the direct effect ($c' = -.018$, $SE = .003$). While omitting verbal IQ from the model may result in consistent mediation, doing so would also weaken the effect of age on auditory memory and possibly lead to erroneously finding full mediation when there is a remaining indirect effect being overlooked.

With respect to the outcome variable, visual memory, the total indirect effect of age on through the mediators processing speed, working memory, executive functioning, visual working memory, and verbal IQ was significant as zero was not contained within the 99% confidence interval. Again, the specific indirect effect of verbal IQ ($ab = .003$), when compared to the direct effect ($c' = -.019$) and the indirect effects for the other mediators, had an opposite sign. These findings indicate that verbal IQ is working in the opposite direction of the other mediators. Whereas increasing age is significantly associated with declines in visual working memory, executive functioning and processing speed, which is expected to result in poorer performance on visual memory tasks, age was found to be associated with increased verbal IQ and better visual memory performance. A simple mediation bootstrap, including age as the predictor variable, visual memory composite as the outcome, and the verbal IQ composite as the single mediator showed that the total effect ($c = -.036$, $SE = .004$) was closer to zero than the direct effect ($c' = -.041$, $SE = .004$). This confirmed that when included in the model, verbal IQ increased the effect of age on the outcome variable.

In summary, the findings did not support the hypothesis. The proposed mediators did have a significant total indirect effect on the relationship between age and visual memory, but the total indirect effect on the relationship between age and auditory memory was non-significant. Working memory was found to be a non-relevant mediator of age-related decline in both outcome variables. Inconsistent mediation emerged necessitating further discussion of the specific indirect effects of each proposed mediator. Looking at the specific indirect effects will better define the role of potentially competing indirect effects and enhance our understanding of the mechanisms that underlie age related memory decline.

Specific Indirect Effects

Hypothesis II

The next hypothesis under investigation asserted that the specific indirect effect of processing speed on the relationship between age and auditory and visual episodic memory, after controlling for the indirect effect of working memory, executive functioning, visual working memory, and verbal IQ would be statistically significant at the .01 level. The multiple mediation bootstrap statistical methodology provided the confidence intervals for the specific indirect effects of each mediator in the model, which are summarized in Tables 5 and 6.

Table 5
Indirect Effects, Magnitudes, and Contrasts for Age-related Auditory Memory Change

	Bootstrapping product of coefficients		99% CI	
	Point Est. (*ab*)	S.E.	LL	UL
Indirect Effects				
Processing Speed	.002	003	-.005	.008
Executive Functioning	-.001	.002	-.008	.005
Working Memory	-.001	.001	-.005	.001
Visual working Mem.	-.003	.003	-.011	.005
Verbal IQ	.002	.001	.000	.008
Total Indirect	-.002	.004	-.011	.008
Effect Sizes				
Processing Speed	.042	.066	-.131	.223
Executive Functioning	-.039	.067	-.226	.134
Working Memory	-.029	.028	-.134	.019
Visual Working Memory	-.083	.084	-.314	.138
Verbal IQ	.062	.036	-.000	.204
Total Indirect Effect Size	-.048	.091	-.292	.202
Contrasts				
VIQ vs. PS	.001	.003	-.007	.009
VIQ vs. WM	.003	.001	.000	.008
VIQ vs. VWM	.005	.003	-.004	.014
VIQ vs. EF	.004	.002	-.003	.010
PS vs. WM	.003	.003	-.004	.011
PS vs. VWM	.005	.004	-.007	.017
PS vs. EF	.003	.004	-.007	.013
WM vs. EF	.002	.003	-.007	.010
WM vs. VWM	.000	.003	-.007	.007
VWM vs. EF	-.002	.005	-.014	.012

Note. S.E. is Estimated Standard Error. LL is Lower Limit. UL is Upper Limit. CI is Bias Corrected Confidence Interval

While increasing age was significantly related to declines in the processing speed composite (*B* = -.026, *SE* = .004, p=<.000), there was a non-significant negative relationship between the processing speed and auditory memory composites (*B* = -.061, *SE* = .089, p>.1), after controlling for the other mediators. The product of this *a* and *b* path calculated for 5000 samples and averaged across resulted in an indirect effect of (*ab* = .001) with a 99% CI [-.005, .008]. As zero was contained within the confidence interval, the specific indirect effect of processing speed on the relationship between age and auditory memory, after controlling for the other mediators was non-statistically significant.

With respect to the specific indirect effect of processing speed on the relationship between age and visual memory, age was significantly related to the processing speed composite (*B* = -.026, *SE* = .004, p=<.000). There was a non-significant positive relationship between the processing speed and visual memory composites (*B* = .156 *SE* = .094, p=.10), after controlling for the other mediators. The indirect effect was (*ab* = -.004) with a 99% CI [-.013, .002]. As zero was contained within the confidence interval, the specific indirect effect of processing speed on the relationship between age and visual memory, after controlling for the other mediators was non-significant. Therefore, the hypothesis was not supported by the results.

Hypothesis III

In examining the specific indirect effects it was hypothesized that the indirect effect of working memory on the relationship between age and both auditory and visual episodic memory, after controlling for the indirect effect of processing speed, executive functioning, visual working memory, and verbal IQ would be statistically significant at the .01 level. The confidence intervals for the specific indirect effects of each mediator in the model are summarized in Tables 5 and 6.

The relationship between age and the working memory composite (*B* = -.007, *SE* = .004, p=>.10), as well as the relationship between the working memory and auditory memory composites after controlling for the other mediators (*B* = .164, *SE* = .097, p>.05) were not significant. The specific indirect effect was (*ab* = -.001) with a 99% CI [-.005, .001]. As zero was contained within the confidence interval, the specific

Table 6

Indirect Effects, Magnitudes, and Contrasts for Age-related Visual Memory Change

	Bootstrapping product of coefficients		99% CI	
	Point Est. (*ab*)	S.E.	LL	UL
Indirect Effects				
Processing Speed	-.004	.003	-.013	.002
Executive Functioning	.000	.003	-.008	.009
Working Memory	.001	.001	-.001	.004
Visual working Mem.	-.016	.004	-.029	-.007
Verbal IQ	.003	.002	.000	.009
Total Indirect	-.016	.005	-.030	-.004
Effect Sizes				
Processing Speed	-.072	.046	-.228	.029
Executive Functioning	.001	.056	-.130	.165
Working Memory	.009	.016	-.025	.079
Visual Working Memory	-.289	.071	-.516	-.129
Verbal IQ	.059	.030	.004	.184
Total Indirect Effect Size	-.291	.080	-.500	-.075
Contrasts				
VIQ vs. PS	.007	.003	.000	.019
VIQ vs. WM	.003	.002	-.001	.009
VIQ vs. VWM	.019	.004	.009	.032
VIQ vs. EF	.003	.003	-.006	.011
PS vs. WM	-.005	.003	-.016	.002
PS vs. VWM	.012	.005	-.001	.027
PS vs. EF	-.004	.005	-.017	.007
WM vs. EF	.017	.005	.007	.030
WM vs. VWM	.000	.003	-.009	.009
VWM vs. EF	-.016	.006	-.033	-.003

Note. S.E. is Estimated Standard Error. LL is Lower Limit. UL is Upper Limit. CI is Bias Corrected Confidence Interval indirect effect of working memory on the relationship between age and auditory memory, after controlling for the other mediators was non-significant.

For the outcome variable visual memory, age was again not significantly related to the working memory composite (*B* = -.007, *SE* = .004, p=>.10), and there was a non-significant negative relationship between the working memory and visual memory composites (*B* = -.077, *SE* = .103, p>.10), after controlling for the other mediators. The specific indirect effect was (*ab* = .001) with a 99% CI [-.001, .004]. As zero was contained within the confidence interval, the specific indirect effect of working memory on the relationship between age and visual memory, after controlling for the other mediators was non-significant. The hypothesis was not supported by the results.

Hypothesis IV

Next, it was hypothesized that the specific indirect effect of the executive functioning averaged composite on the relationship between both age and auditory and visual episodic memory, after controlling for the indirect effect of processing speed, working memory, visual working memory, and verbal IQ would be statistically significant at the .01 level. The confidence intervals for the specific indirect effects of each mediator in the model are summarized in Tables 5 and 6.

Again, the hypothesis was not supported by the results. The relationship between age and the executive functioning composite (*B* = -.021, *SE* = .003, p =.000) was significant while the relationship between the executive functioning and auditory memory composites after controlling for the other mediators (*B* = .069, *SE* = .135, p>.50) was non-significant. The specific indirect effect was (*ab* = -.001) with a 99% CI [-.008, .005]. As zero was contained within the confidence interval, the specific indirect effect of the executive functioning composite on the relationship between age and auditory memory, after controlling for the other mediators was non-significant.

For the outcome variable, visual memory, age was again significantly related to the executive functioning composite (*B* = -.021, *SE* = .0032, p =.000), but there was a non-significant negative relationship between the executive functioning and visual memory composites (*B* = -.003, *SE* = .144, p>.10), after controlling for the other mediators. The specific indirect effect was (*ab* = .000) with a 99% CI [-.008, .009]. As zero was contained within the confidence interval, the specific indirect was non-significant.

Hypothesis V

Next under investigation was the hypothesis that the specific indirect effect of the visual working memory averaged composite on the relationship between age and auditory and visual episodic memory, controlling for the indirect effect of processing speed, working memory, executive functioning, and verbal IQ would be statistically significant at the .01 level. The multiple mediation bootstrap statistical methodology provided the confidence intervals for the specific indirect effects of each mediator in the model, which are summarized in Tables 5 and 6.

The hypothesis was not supported by the results. The relationship between age and the visual working memory composite (*B* = -.032, *SE* = .004, p =.000) was significant while the relationship between the visual working memory and auditory memory composites after controlling for the other mediators (*B* = .096, *SE* = .105, p>.10) were non-significant. The specific indirect effect was (*ab* = -.003) with a 99% CI [-.011, .005]. As zero was contained within the confidence interval, the specific indirect effect was non-significant.

However, for the outcome variable, visual memory, age was significantly related to the visual working memory composite (*B* = -.032, *SE* = .004, p =.000), and there was a significant positive relationship between the visual working memory and visual memory composites (*B* = .507, *SE* = .111, p =.000), after controlling for the other mediators. The specific indirect effect was (*ab* = -.016) with a 99% CI [-.029, -007]. As zero was not contained within the confidence interval, the specific indirect of the visual working memory composite on the relationship between age and visual memory, after controlling for the other mediators, was significant.

Hypothesis VI

Regarding the verbal IQ composite, it was hypothesized that the specific indirect effect of the verbal IQ on the relationship between age and both auditory and visual episodic memory, after controlling for the indirect effect of processing speed, verbal working memory, executive functioning, and visual working memory would be statistically significant at the .01 level. The confidence intervals for the specific indirect effects of each mediator in the model, which are summarized in Table 5 and 6.

The relationship between age and the verbal IQ composite (*B* = .010, *SE* = .004, p =.01) was significant; while the relationship between the verbal IQ and auditory memory composites after controlling for the other mediators (*B* = .231, *SE* = .107, p<.05) were significant at the .05 level. The specific indirect effect was (*ab* = .002) with a 99% CI [.000, .008]. As zero was not contained within the confidence interval, the specific indirect was considered significant.

Similarly for the outcome variable visual memory, age was again significantly related to the verbal IQ composite (*B* = .010, *SE* = .004, p =.01) and there was a significant positive relationship between the verbal IQ and visual memory composites (*B* = .338, *SE* = .113, p <.01), after controlling for the other mediators. The specific indirect effect was (*ab* =.003) with a 99% CI [.000, .009]. As zero was not contained within the confidence interval, the specific indirect of the verbal IQ composite on the relationship between age and visual memory, after controlling for the other mediators was significant. This hypothesis was fully supported by the results.

In summary, neither processing speed, working memory, visual working memory, nor executive functioning significantly mediated the relationship between age and auditory memory. Only verbal IQ, for which the specific indirect effect worked in opposition to the other potential mediators, has a significant indirect effect on age-related auditory memory change. Despite the inconsistent mediation introduced by the specific indirect effect verbal IQ, which was significant at the .01 level, the magnitude of the specific indirect effect of visual working memory appeared to be large enough to remain significant and mediate the relationship between age and visual memory.

Contrasting the Specific Indirect Effects

Hypothesis VII

Contrasting the strength of the proposed mediators against each other in pair wise comparisons, it was purported that the magnitude of the specific indirect effects of processing speed, verbal working memory, visual working memory, executive functioning, and verbal IQ were not of equal size and therefore differed from each other at the .01 significance level. It was concluded that this hypothesis was not fully supported by the results.

Preacher and Hayes (2008) emphasize the importance of reporting effect sizes prior to asserting whether the significant contrasts indicate the presence of a stronger or larger specific indirect effect. The PROCESS Macros (Hayes, 2013) provides several measures of effect size. For instance, the indirect and specific indirect effects, as the product of two regression coefficients (i.e., *ab* paths), themselves represent the magnitude of the effect of the independent variable on the dependent variable through the mediator(s). However, the product is the result of unstandardized coefficients and therefore not a robust or comparable measure of effect size in the context of changing scales.

In addition, the output provides an index of explained variance (e.g., R^2 and adjusted R^2) to quantify how the overall mediation model accounts for variance in the outcome. Unfortunately, this unit takes the focus away from understanding the underlying process itself, especially in models containing multiple mediators. Furthermore, according to Preacher and Kelly (2011), explained variance has several limitations. The most salient being that it is dependent on the maximum amount of variance that can be explained, which often differs across studies, populations, and variables measured or observed. Such a limitation precludes the use of R^2 indices for meaningfully comparing effects.

Therefore, the reported effect sizes were chosen based on the criteria provided by Preacher and Kelly (2011), which note that "a good effect size" should be: (1) scaled on a meaningful and/or standardized, metric; (2) amenable to the construction of confidence intervals; and (3) independent of sample size. The *Index of Mediation or Completely Standardized Indirect Effect* is essentially a transformation of an effect expressed in terms of the standard deviation change in the outcome variable after one standard deviation change in the independent variable, and is equivalent to the standardized regression coefficients for the direct and indirect effects (Hayes, 2013). These indirect effect sizes are interpreted as the standard deviation change that occurs in auditory or visual memory performance for every one standard deviation change in age (*SD* = 16 years), as a result of the effect of age on the mediators. The effect sizes and confidence intervals are summarized in Tables 5 and 6.

Finally, the Hayes PROCESS Macros provide pairwise contrasts between the magnitudes of the specific indirect effects in the model. The statistical procedure calculates the difference between the two specific indirect effects across 5000 resamples, which is then divided by the standard error. A 99% confidence interval is created and the specific indirect effects are considered statistically different if the established contrast confidence interval does not include zero.

The confidence intervals for the contrasts between the magnitudes of the specific indirect effects on the relationship between age and auditory memory are summarized in Tables 5. Because zero is contained in the confidence interval for the pairwise comparisons between processing speed, executive functioning, working memory, and visual working memory, those indirect effects cannot be distinguished in terms of their size. Only the magnitude of the specific indirect effect of verbal IQ differed significantly from that of working memory at the .01 level.

Integrating this information with the effect sizes listed above, it can be concluded that not only does the magnitude of the specific indirect effect of verbal IQ (*ab* = .002) differ significantly from that of working memory (*ab* = -.001), but the specific indirect effect of verbal IQ is significantly larger than that of working memory at the .01 level. The auditory memory composite decreased (*SD* = .029) for one standard deviation increase in age, as a result of the mediated effect of working memory. On the other hand, the auditory memory composite increased (*SD* = .062) because of the mediating effect of verbal IQ and. This means that the specific indirect effect of age through verbal IQ resulted in a significantly larger standard deviation change in auditory memory than it did through working memory.

The confidence intervals for the contrasts of the specific indirect effects on the relationship between age and visual memory are summarized in Table 6. Zero was contained in the confidence interval for the pairwise comparisons between the specific indirect effects processing speed and executive functioning, working memory, or visual working memory – indicating that the magnitude of the indirect effects could not be distinguished at the .01 level. The contrast between the processing speed and verbal IQ 99% CI [.007, .031] was significant. In addition, the contrasts between the specific indirect effects of the visual working memory composite and the verbal IQ 99% CI [.010, .034]; working memory 99% CI [.007, .030] and executive functioning 99% CI [-.033, -.004] composites were significantly different in terms of magnitude.

The effect size and contrast results for the visual memory outcome, indicate that the visual memory composite increased (*SD* = .001); (*SD* = 009); (*SD* = .059) for every one standard deviation increase in age, as a result of the mediating effect of executive functioning, working memory and verbal IQ, respectively. Visual memory decreased a (*SD* = .289) and (*SD* = .072) for one standard deviation increase in age, as a result of the respective mediating effect of visual working memory and processing speed. The magnitude of the specific indirect effect of visual working memory was larger than that of verbal IQ in the relationship between age and visual memory at the .01 level. Verbal IQ had a significantly larger specific indirect effect size than processing speed. Lastly, the magnitude of the specific indirect effect of visual working memory was significantly larger than that of executive functioning and verbal working memory at the .01. This means that the specific indirect effect of age through visual working memory resulted in a significantly larger standard deviation change in visual memory than it did through verbal IQ, working memory, and executive functioning.

CHAPTER V

Discussion

The purpose of the current study was to examine and to clarify the mechanisms through which age is related to auditory and visual episodic memory, in a normal population aged 16-70 years. Previous studies have not accounted for the evidence that age-related memory decline differs across auditory and visual memory domains (Hale et al., 2011), nor have they accounted for other potential intervening variables such as intelligence or visual compared to verbal processing capacity, which have been found to be related to memory and cognition. The current study explored the relationship between age and memory to understand whether processing speed, verbal working memory, visual working memory, executive functioning, and verbal IQ collectively and separately mediated age-related decline in auditory and visual memory.

Total Indirect Effect

Hypothesis I

The first hypothesis stated that within a neuropsychological sample of normal adults, the relationship between age and auditory and visual episodic memory would be mediated by cognitive processing speed, working memory, visual working memory, executive functioning, and measured verbal IQ, as measured by a non-age corrected composite z-score, at the .01 level. The present findings did not support this hypothesis.

The findings revealed a significant indirect effect of age on visual memory through the speed at which information can be processed; the capacity to process and manipulate information; the ability to categorize, inhibit and perform abstraction; and the ability to comprehend verbal information. On the other hand, the five mediators together did not significantly mediate the age-related changes that were observed in auditory memory. The results were unexpected for several reasons, primarily because it was expected that the effect of the five mediators would be significant for both visual and auditory memory or for neither of them.

In both analyses, auditory and visual recall were observed to decline with age. In addition, for both outcomes, age was significantly predictive of changes in processing speed, visual working memory, executive functioning, and verbal IQ. This suggests that the "*a*" and "*c*" paths were quite similar across models while the "*b*" paths between the mediators and outcomes were unique enough to contribute to different total indirect effects. The results are significant to researchers and clinicians alike because they implicate differences in the maturation of memory abilities across sensory modalities; introduce a competing underlying process model that builds on the field's understanding of age-related memory decline; and support the contributions of verbal IQ in the discussion of age-related memory decline beyond the concept of "cognitive reserve".

First, while it was not the explicit goal of the present analysis to examine modal differences in the rate and processes underlying age-related memory decline, the results did demonstrate that the processes underling age-related memory loss and forgetfulness differ between sensory domains. This was facilitated by the use of a composite measure of verbal-auditory and visual-graphic memory, which was intended to account for any possible modal differences in memory change across the adult age spectrum that have been studied inconclusively in the literature (Hale et al., 2011; Kemps & Newson, 2006; Park et al., 2002; Salthouse, 1995). This composite, which was discussed in the Method section, allowed for an exploration regarding how performance on tasks with a verbal encoding demand were uniquely influenced by age-related changes in processing speed, verbal working memory, executive functioning, visual working memory, and verbal IQ. The results could then be discussed in terms of how they differed from the mechanisms underlying changes in performance on tasks with a visual-graphic encoding demand.

The findings, while not fully supportive of the hypothesis, did reveal an inverse relationship between age and both auditory and visual memory. After controlling for processing speed, working memory, executive functioning, visual working memory, and verbal intelligence, an attenuation of the direct relationship between age and memory emerged, which reflected the presence of an indirect effect in which the five mediators, to some extent, served as mechanisms through which age was related to memory. However, the total influence of the mediators on auditory memory was not significant. For visual memory, the mediators did result in a significant total indirect effect. Evidently, there was some variability in the combined "*ab"* paths across the two modes of memory, where the "*ab"* paths culminate in a significant indirect effect for visual memory and a non-significant one for auditory memory.

These modal differences hint at the complex interplay between the mediating variables included in the model, which was also implicated by the inconsistent mediation that emerged. Moreover, the results demonstrated that: (a) age-related decline in auditory and visual memory commonly occur; (b) the various factors that underlie age-related changes in memory may be dependent on the modality of memory (i.e., visual vs. auditory); (c) differentiation exists between declines in visuospatial and auditory memory at the level of the underlying mechanisms; and (d) the modal difference are not as readily observed or measured in analyses of the direct relationship of age and memory.

An advantage of the present mediation analysis is that it accounts for five mediators in a model that was tested using both visual and verbal memory outcomes. As such, the analysis offers more information than direct effect or simple mediation models regarding the interplay of various cognitive functions. Based on the results of the present study, such interplay across the adult life span appears to be contingent on the mode of the memory that is engaged by the demands of the task. As research in the area of aging continues to focus on understanding the interrelationships among basic and higher order cognitive resources, the present results indicate that modal differences must be examined as well.

For instance, the present examination found that the amount of variance in auditory memory that was accounted for by age was not equivalent to the variance in visual memory that age accounted for. The regression coefficients for the direct effect of age on visual memory were larger than that of auditory memory – meaning that increasing age was responsible for greater declines in visual memory than in auditory memory within the same sample of non-demented individuals. Naturally, with more variance available to account for in the visual memory model, the five-mediator model was found to have a larger mediating effect on visual memory over auditory memory abilities. The results demonstrated that as age increases, an individual’s ability to encode and to retrieve visual information declines more readily than auditory encoding and recall. This highlights the greater sensitivity of visual memory to age than auditory memory, and indicates some differentiation in the architecture of memory, particularly as it relates to age and modality, does exist.

The results are informative in the assessment of subjective memory complaints and actual memory disorders because they identify how various cognitive functions behave in concert and the extent to which these processes influence memory performance across adulthood. Since asymmetrical changes in memory performance were found to be associated with age, these findings indicate a higher age-sensitivity of visual compared to auditory encoding and retrieval. As a result, researchers and clinicians may benefit from developing a more functional understanding of the disparities in auditory and visual memory performance across the life span, particularly as it may aid in the distinction of age-related decline from more pathological decline.

In addition, significant results emerged in which visual but not auditory memory was mediated by processing speed, working memory, visual working memory, executive functioning, and verbal IQ. This reveals that visual as well as verbal encoding and retrieval are somewhat distinct systems with underlying processes that are domain-specific. Essentially, as one ages, the underlying cognitive processes have vastly different effects across the various modes of memory. This research may aid in refining the scientific and clinical conceptualization of deficits as normal age-related decline, mild cognitive impairment, or an early dementing/pre-Alzheimer's process. Particularly when poorer performance is identified in visuospatial and right-hemisphere memory tasks and not in verbal and left-hemisphere memory tasks.

Secondly, the present findings were not supportive of the hypothesis, because it purported that the five-mediator model would be significant for both outcome variables. However, as noted above, this was not the case. Age-related change in auditory memory was not mediated by processing speed, verbal working memory, executive functioning, and visual working memory, while age-related change in visual memory was. The results, when presented as a whole in this omnibus examination appears simple and interpretable as the absence of mediation. However, in detail, the findings are complex. As such, the presence of non-confirmatory results requires an interpretation of the specific indirect effect of each mediator in the auditory and visual memory model.

For example, inconsistent mediation emerged in the auditory memory model where the coefficients for two of the five indirect pathways revealed that through these two mediators, increasing age was related to better auditory memory performance. Three of the five *ab* pathways showed that through these three mediators, increasing age was related to poorer auditory memory. This can be otherwise thought of as counteracting or opposing meditational factors on the relationship between age and auditory memory. Essentially, the pathways going from age to auditory memory, via processing speed and verbal intelligence, compensated for the pathways leading to age-related cognitive decline through working memory, visual working memory, and executive functioning. Because the mediation effects associated with age-related memory decline were not large or significant enough to overcome the opposing factors of each other, the five mediators in concert did not have a statically significant effect. Therefore, while there is a statistically non-significant total indirect effect, another possible explanation for the results is that competing underlying processes characterize age-related change in auditory memory. As such, the hypothesis that overall mediation would occur, may be erroneously anchored in earlier theories of mediation that have oversimplified the relationship between age and memory.

For visual memory, three of the five indirect pathways revealed that increasing age was related to better visual memory performance. Two of the five *ab* pathways showed that through these two mediators, increasing age was related to poorer visual memory. The pathways through verbal intelligence, executive functioning, and working memory to visual memory compensated for the pathways going through visual working memory and processing speed that resulted in age-related visual memory decline. However, in this case, the overall mediation effects commonly associated with age-related memory decline were large enough to overcome the compensatory factors. While total indirect effect of the five mediators was statistically significant, the interpretation that mediation occurred minimizes the complexity of the interplay between the variables in the model. A possible interpretation, which needs further exploration, is that declines in visual memory as individuals age are aggravated by declines in capacity and processing and mitigated by certain acquired abilities (i.e., verbal IQ).

Notably, a number of the variables in the model behaved in a positive direction while others trended in a negative direction. These findings have theoretical implications, particularly as they reveal a complex interplay of mitigating and aggravating cognitive functions that fundamentally underlie age-related attenuation of memory abilities. The therapeutic promise of the present study is that it inspires a paradigm shift in how clinicians and researchers think about age-related cognitive decline. The findings enable clinicians to better understand the relationships between cognitive and neuropsychological functions associated with age. In the present study, age-related decline in auditory and visual memory, when examined in terms of the process underlying such decline, is complex and interactive. Put another way, the results reveal that as individual's age, their ability to encode, store, and retrieve auditory information declines. However, along the adult developmental spectrum, both the slower rate at which information is processed and increased or practiced verbal comprehension abilities may support better auditory memory, and essentially offset the weakening of auditory memory caused by a reduced capacity for manipulating verbal information and a decline in executive functioning as we age.

For visual memory, the interaction between the compensatory and aggravating functions provided some indicate that age related changes in one's ability to store and retrieve visual-graphic information. The ability to encode, store and retrieve visual information declines as individuals age in part due to a reduced capacity to process and to manipulate visual information, as well as slowing in the rate at which information can be processed. Knowing this, rehabilitation professionals and neuropsychologists can introduce therapies and techniques that maintain those functions that mediate age-related cognitive decline while building upon the underling compensatory factors throughout adulthood.

Of equal significance, and salient to the interpretation of these findings, was the inclusion of verbal intelligence in the model. In an omnibus analysis, it was concluded that significant mediation did not occur in the auditory memory model. However, after examining all of the *ab* paths, opposing directions were identified, which was especially evident with the verbal IQ variable. In both the auditory and visual memory model, verbal IQ increased with age and supported better memory performance.

A possible interpretation of the results is that due to the inclusion of verbal IQ the combination of the *ab* paths was such that the mitigating factors worked to a lesser extent to support better memory performance than did the aggravating factors. The result was overall significant mediation in visual memory model. For the auditory memory model, age-related increases in verbal IQ that supported better memory performance were larger than the negative indirect effects of the other factors in the model thereby resulting in a non-significant total indirect effect.

The above interpretation suggests that age-related cognitive decline is better understood when the examination includes the influence of one's ability to listen and to understand the meaning of written or spoken information, to understand the relationships between language concepts, and to analyze and to solve language-based literary, interpersonal, or logical problems. While the neuropsychology community recognizes the relevance of verbal IQ in clinical practice, very few studies have discussed or examined the influence of verbal IQ, crystallized intelligence, or verbal abilities on age-related changes in memory. However, it was asserted that this might be a relevant and necessary part of the discussion on age-related memory decline.

Beyond the concept of cognitive reserve, which hypothesizes why those with higher IQ, education, or occupational attainment evidence less severe clinical or cognitive changes in the presence of age-related changes, the findings suggest that the compensatory influence of higher verbal IQ is among the processes that underlie age-related changes in memory across the adult lifespan. Essentially, verbal IQ is a very salient cognitive domain that contributes to the interplay underlying cognitive aging. The results expand upon early conceptualizations of age-related cognitive changes as unidirectional (i.e., that as age increases, cognitive abilities decrease).The findings reveal that along the adult age spectrum, individuals acquire or concretize certain abilities that facilitate better cognition and memory, while at the same time other abilities degrade to cause reduced cognition and memory.

It is consistently observed in the aging and cognition literature that with increasing age there are greater declines in memory performance. Taking this into account, a standard in neuropsychological practice has been the use of age-corrected normative data. This should remain a standard of practice in the evaluation of older adults' memory complaints; however, the present findings support that increased age is also associated with acquired verbal abilities. It is important for clinicians to note that cognitive changes along the adult spectrum are more complex than previously modeled. Furthermore, the results of the present study implicate modal differences in age- related memory decline, specifically in the processes involved in the age-memory relationship. For clinicians, these findings indicate that an assessment of both visual and verbal working memory and recall may offer greater understanding of the individual's memory difficulties and further refine what recommendations would be helpful in reducing the functional impact of these issues.

Finally, the translational relevance of the present findings is that it offers a more functional understanding of age-related memory decline for clinicians, which may prove useful, particularly in differentiating normal aging from mild cognitive impairment and early dementia. There is substantial interplay between cognitive functions that underlie memory, with verbal IQ serving as a compensatory factor in age-related cognitive decline, of which clinicians must be aware. While poor performance in one area of cognition may subserve and explain poor performance in another (i.e., memory), it is important to also integrate the role of acquired verbal abilities, which may be contributing to better encoding and retrieval of information.

Specific Indirect Effects

Hypothesis II

The next hypothesis under investigation asserted that the specific indirect effect of processing speed on the relationship between age and auditory and visual episodic memory, controlling for the indirect effect of verbal working memory, executive functioning, visual working memory, and verbal IQ would be statistically significant at the .01 level. This hypothesis was not supported by the results.

This was not expected considering that the immediate and delayed logical memory subtests involve auditory processing of detailed information that is verbally presented. The task requires rapid processing of large amounts of information, to which the individual has not been previously exposed. Logical memory is also a time-controlled task where limitations on the person’s cognitive proficiency, particularly the slowing that is commonly associated with aging, impacts the cognitive operation of remembering. When asked to recall the details from memory, individuals, particularly those relying on rote memory, are only able to retrieve what was originally encoded. The immediate and delayed verbal paired associates subtests is a task that involves both the encoding of auditory information, forming associations, memorizing word pairings, and list learning. The completion of multiple processes (i.e., encoding words and making associations) in a single task is more difficult to perform for individuals who are unable to perform the tasks quickly and efficiently. As these subtests form the auditory memory composite outcome variable, it is logical to purport that age related changes in auditory memory could be explained by changes in processing speed abilities.

The findings revealed that as we age, the speed at which the human brain is able to perform the mechanical or chemical operations necessary in performing tasks slows.

This age-related degradation in processing speed occurs parallel with the deterioration of one's abilities to encode aural information, process it, retain it, and recall it later. However, cognitive functions are not performed in isolation of each other; rather, there is interplay among the various functions of the brain. For instance, visual disruptions would negatively affect visual spatial memory just as a disruption in the ability to comprehend language would affect any cognitive task in which the directions were orally presented. Whether processing speed mediates age-related decline in auditory memory would be contingent on the impact of other cognitive functions that are considered possible mediators of age related decline in auditory memory. Therefore, the present study endeavored to isolate the unique contribution of processing speed, after accounting for the influence of verbal working memory, executive functioning, visual working memory, and verbal intelligence.

The indirect effect for processing speed, after controlling for the indirect effect of the other mediators in the model proved to be non-significant. As such, age related changes in auditory memory were not significantly mediated by age related declines in processing speed. When isolated, the specific indirect effect of processing speed was non-significant at the specified alpha level and revealed an upward trend in auditory memory despite the presence of age-related slowing in processing speed. Essentially, the present results indicate that processing speed becomes a less salient mechanism when included in a model with verbal working memory, visual working memory, executive functioning, and verbal intelligence. These findings reveal that the rate at which the brain performs simple perceptual or cognitive tasks is not a central determinant for how efficiently a person encodes sensory input or engages in other cognitive functions (i.e., remembering, comprehending, or manipulating information).

With respect to the specific indirect effect of processing speed on the relationship between age and visual memory, again there was a declining trend in both processing speed and visual memory with increased age. For the immediate and delayed designs subtest, which comprise the visual memory outcome variable, time is an important component. Visual information processing of the designs and their location requires rapid assessment of the details and synthesis into a gestalt. In addition, visual stimuli are presented in the visual reproduction subtest for a limited time, requiring an individual to encode a number of details quickly and to recreate the design on a sheet of paper. Considering the time component of the visual memory composite outcome, as well as the presence of age-related cognitive decline in both processing speed and visual memory, it was surprising to find that after controlling for the other mediators in the model, processing speed had a non-significant specific indirect effect. The results were not completely commensurate with those of the auditory memory model because visual memory did show a declining trend as age increased and processing speed slowed. More specifically, age-related declines in visual memory due to low speed of encoding and/or rate of rehearsal for visual information were observed. Statistically, the findings were small and non-significant, indicating that processing speed is not a salient mediator of age-related memory decline.

For researchers and clinicians, the present findings are an anomaly, but not in the sense that an error has occurred. Rather, these results demonstrate the complexities and nuances of age-related memory decline. Considering the tangle of cognitive abilities that interact and coalesce to form a functional brain, it is a logical conclusion that the processes underlying-age related cognitive decline are complex. Therefore, the present findings demonstrate that within a comprehensive model, as the one presented in this study, processing speed does not hold up after accounting for other established and under-researched factor and verbal intelligence.

In the area of cognitive remediation and rehabilitation, the results have clinical utility by revealing that processing speed may not be an appropriate target for improving age-related decline in memory. Currently, cognitive rehabilitation/remediation interventions for age-related and other cognitive impairment employ either a restorative approach, in which the focus is on enhancing or restoring cognitive abilities, targeting protective factors, and maximizing neuroplastic mechanisms (e.g., “brain training”), or a compensatory approach, where functional compromises are targeted and strategies are implemented to compensate for impairment. Approaches may target a single domain or multiple domains in an effort to reduce cognitive decline. Clinicians and rehabilitation personnel evaluate the effectiveness of treatments in terms of their long-term and immediate impact on measured /objective cognitive performance, as well as their effect in reducing subjective cognitive complaints, improving daily functioning, enhancing quality of living, and reducing the severity of neuropsychiatric symptoms. Consequently, it is crucial to understand what functions decline with age, but more importantly the processes that underlie such decline in order to identify domains that therapies should target.

The therapeutic promise of the present study is that it demonstrates that declines in memory are not simply the manifestation of slowed processing speed preventing older individuals from encoding, rehearing, or learning information needed for later use. Essentially, there are cognitive domains other than processing speed that are more effective targets for remediation therapies intended to restore age-related decline in auditory and visual memory.

In neuropsychological assessment, declines in processing speed are often considered a hallmark of age-related decline. While the present findings support meaningful changes in processing speed along the adult life span, they also highlight that such decline may not be associated with poorer memory performance. Because the processes underlying cognitive aging are complex and competing, low processing speed scores must be considered in the context of other abilities. Furthermore, memory decline, particularly among the aging population, may best be informed by performance in areas other than processing speed.

Hypothesis III

In examining the specific indirect effects, it was hypothesized that the mediated effect of verbal working memory on the relationship between age and auditory and visual episodic memory, controlling for the indirect effect of processing speed, executive functioning, visual working memory, and measured verbal IQ, would be statistically significant at the .01 level. The current findings did not support this hypothesis.

The inclusion of working memory into this multiple mediation model was necessary to examine the cognitive processing theory of age-related decline, which considers two factors of processing (i.e., speed and capacity) as the mechanisms underlying age related cognitive decline. The advantages of the present study are that it includes measures of visual working memory, executive functioning, and verbal intelligence, which are sensitive to aging. By doing so, the present study accounted for other salient mediators of age-related memory change, which when included in the model revealed processing speed to be a non-significant mediator of age related memory decline. The second component of the cognitive processing theory, capacity, was examined.

Not only was verbal working memory not related to age, but changes in an individual's capacity for attention, mental manipulation, and short-term storage were unrelated to an individual ability to store or recall auditory or visual information over time. While one could have considered the working memory composite irrelevant to the present examination of mediators of age-related cognitive decline and excluded the variable from both models at the outset it was ultimately concluded that the working memory composite should remain in the model. Subsequently, the unique contribution of working memory was found to be small and statistically non-significant, revealing working memory to be non-salient mediator of age-related decline in auditory and visual memory.

The findings expand the understanding of researchers and clinicians of the cognitive processing model. The present study used a composite variable that included subtests from the WAIS-IV. More specifically, the digit span subtest, which is a commonly used measure of attention, alertness, and mental processing capacity, as well as the arithmetic subtest, which assesses sequencing ability, numerical reasoning, speed of numerical manipulation, concentration, and attention comprised the working memory composite. The purpose of this composite was to quantify an individual's capacity to input, mentally manipulate, and store information for the duration that it is needed to perform mental activities. As the composite variable was solely comprised of verbal tasks, it was considered a measure of processing capacity for verbal information. A measure of non-verbal working was included as well, and discussed later in the chapter.

It was believed that due to the shared modality of auditory episodic recall and the auditory-based measures of working memory, as well as the attention component of working memory, which is a prerequisite for information storage, age-related changes in verbal working memory would indirectly influence age-related changes in episodic memory. However, the indirect effect of verbal working memory, after controlling for the "*ab"* pathways of the other mediators in the model proved to be non-significant. As such, age-related changes in auditory memory were not significantly mediated by age-related declines in verbal working memory. When isolated, the specific indirect effect of working memory was non-significant at the specified alpha level despite revealing a declining trend in both verbal working memory and auditory memory. The current results indicate that working memory becomes a less salient mechanism when included in a model with visual working memory, executive functioning, and verbal intelligence, as it was non-significant. These findings further reveal that the capacity of the brain to encode, to rehearse, and to manipulate spans of non-complex information is not a central determinant for how efficiently a person encodes sensory input or conducts other cognitive functions (i.e., organization or retrieval).

With respect to the specific indirect effect of verbal working memory on the relationship between age and visual memory, again there was a declining trend in both working memory and visual memory as age increases. Visual information processing of the designs and their location requires attention, organization, and mental manipulations of information. In addition, visual stimuli are presented in the visual reproduction subtests for a limited time, requiring the individual to encode and to store a number of details quickly and then recreate the design on a sheet of paper. However, despite the capacity component of the visual memory composite outcome, there was no significant age-related cognitive decline in working memory.

These results have theoretical significance as they demonstrate the low susceptibility of verbal working memory capacity to age. The results indicate that there is little attenuation in adults' resources for manipulating verbal information as they age. When included in the present comprehensive model, individuals between 16 to 70 years of age may be equally efficient at inhibiting tangential or extraneous information, discarding irrelevant input, and restraining perseverative or inappropriate responses. In the absence of this breakdown in attention and short-term storage of information throughout adulthood, the working memory system does not seem to play a role in mediating changes in an individual's ability to capture needed information or to perform goal-directed responses as we age. Moreover, the present findings demonstrate that among individuals from 16 to 70 years of age, the decline in performance on tasks that require storage, rehearsal, and manipulation of a string of orally presented digits or to mentally solve a series of arithmetic word problems is non-significant.

Because it was beyond the scope of the present study to parse out the indirect effects of the simpler digit span forward from more executive based tasks such as digit span backwards and sequencing the present examination of working memory does not allow for comparison between more effortful verbal working memory tasks in explaining age-related variance in memory function. However, the present findings do underscore the differing contributions of working memory based on the complexity of the tasks that comprise the working memory composite, as well as the sensory modality (i.e., auditory or visual) of the task demands.

With respect to the composition of the working memory composite variable for which the digit span and arithmetic subtests from the WAIS-IV were used. Poor performance on such tasks often reflects poor attention and alertness; impaired sequencing ability; poor numerical reasoning; inability to manipulate numerical information quickly; essentially, poor mental processing capacity. However, the demands placed on non-demented and non-brain injured adults to complete these tasks are relatively low (i.e., immediately recite a span of numbers forward, backward, and in numerical order). The visual working memory composite, which is discussed in greater depth below, is comprised of tasks that draw on visual encoding, spatial organization, and manipulation of novel information (e.g., symbols). While attention and alertness are necessary, the novel nature of the task gives it greater executive burden and difficulty. While the verbal working memory mediator did not have a significant relationship with age or a mediating effect on age-related visual and auditory memory, the visual working memory did yield significant results. This highlights a greater mediating influence for working memory when the task is more complex.

In neuropsychological assessment, declines in working memory are often considered a common finding for older adults reporting memory problems. However, the present findings do not support meaningful changes in verbal working memory throughout adulthood. As such, it was concluded that verbal working memory does not result in poorer memory performance. Because the processes underlying cognitive aging are complex and competing, low verbal working memory scores must be considered in the context of a the demands of a tasks and its complexity. That is, working memory tasks that have less of a cognitive demand, specifically in non-demented adults, are less sensitive to age-related deterioration and may not be appropriate in assessing the subjective memory complaints with which this population may present. These results promote a more functional understanding of memory decline, particularly among the aging population, which is better informed by performance in areas other than verbal working memory.

Furthermore, such differences in the indirect effect of the verbal and visual working memory mediators, with verbal working memory being rendered non-significant, implicate modal variations in age related memory decline, specifically in the processes involved in the age-memory relationship. For clinicians, these findings indicate that an assessment of both visual and verbal working memory and recall may offer greater understanding of the individual’s memory difficulties and further refine what recommendations would be helpful in reducing the functional impact of these issues.

A third explanation for the present results lies in the model tested and the inclusion of cognitive variables that have a greater role in influencing age-related memory change, despite their limited research. The findings revealed substantial interplay between cognitive functions that underlie memory, with verbal IQ serving as a compensatory factor in age-related cognitive decline. In both the auditory and visual memory model, verbal IQ increased with age and supported better memory performance. Age-related increases in one’s ability to listen and to understand the meaning of written or spoken information, to understand the relationships between language concepts, and to analyze and to solve language-based literary, interpersonal, or logical problems, appears to temper the indirect effect of verbal working memory.

Nevertheless, the current findings raise an important consideration for clinicians and researchers alike with respect to test selection and interpretation. Different measures assess storage and processing abilities (i.e., ability to mentally transform and manipulate information) and these measures often range in their complexity and demand. While any given assessment provides a piece of information about a person's working memory abilities, results must be considered in the context of what the examinee was required to perform. Furthermore, because age-related changes in performance on working memory are contingent on task complexity, researchers must incorporate a robust sampling of working memory data to capture the construct fully. Because less complex measures of working memory (e.g. digit span) have been found to be less sensitive to aging than are more complex tasks such as spatial addition, researchers have often resolved to use multiple working memory measure of varying complexity. In the present study, the verbal working memory composite variable can be thought of as a simple measure of working memory in which the demands of the task are limited to how many items can be repeated back in a particular order or how many simple arithmetic problems (requiring addition, subtraction, multiplication, and division) could be accurately solved.

In both research and practice, a common question is whether memory and other cognitive abilities can be enhanced in adults, particularly in older adulthood where declines in cognitive abilities may be observed. The present study reveals that simple verbal working memory abilities do not significantly explain the processes that occur in the aging memory systems. For the rehabilitation and neuropsychology community, this implicates attentional capacity, short-term memory, and simple span capacity as poor targets for remediation.

While a number of cognitive areas have been identified as targets for training, restoring, or enhancing cognitive functioning, working memory has received some support for its role in enhancing fluid intelligence. The findings of the present study provide an explanation for the lack of generalizablity of working memory training as a tool for improving other areas of cognitive functioning. Essentially, the study reveals that working memory does not subserve age-related memory decline. Using a bottom up approach by examining the role of verbal working memory in mediating age-related memory decline in adults, the current findings cast doubt on both the clinical relevance of working memory training programs and their utility as methods of enhancing memory functioning in normal aging healthy adults. While the present findings cannot be generalized to impaired populations, this research demonstrates the necessity of identifying the mechanistic processes of normal adult age-related memory change to which clinicians can compare breakdowns in the functional mechanisms when neuropathology is present.

Hypothesis IV

It was hypothesized that the specific indirect effect of the executive functioning composite on the relationship between age and auditory and visual episodic memory, controlling for the indirect effect of processing speed, working memory, visual working memory, and verbal IQ would be statistically significant at the .01 level.

The inclusion of executive functioning into this multiple mediation model was necessary to examine the utility of the executive decline hypothesis against the processing theory and other relevant variables that are sensitive to aging. The executive decline hypothesis purports that as individual’s age the prefrontal lobes suffer more rapid and progressive changes. Such age-related atrophy in the frontal cortex is thought to result in attenuated functioning of higher order/executive abilities, thereby inspiring decline in related areas of functioning such as memory. Essentially, executive abilities have been theorized to underlie age-related memory change. However, the present results were not supportive of the hypothesis that executive functioning would be informative regarding differences in memory abilities as an individual ages. Rather, the results are informative in that they identify the executive decline hypothesis as being less robust when considered in a more comprehensive mediation mode.

Another area of consideration when interpreting these results is that the executive functioning construct is an umbrella term that encompasses functions for which the frontal and pre-frontal cortex are neural substrate. As such, it was essential that the observable variable quantifying executive attributes reliably and validly measure the construct. An advantage of the present analysis was that executive functioning was measured using a composite variable containing non-age corrected z-scores. Measures included: (1) a task of visual scanning speed, psychomotor speed, sequencing ability, visual attention, concentration, and cognitive flexibility (i.e., TMT-B), (2) a measure of non-verbal concept formation and the ability to shift and to maintain problem-solving strategies (i.e., CAT-CV), and (3) a task that is often considered the “gold standard” measure of executive abilities that assesses the ability to form abstract concepts, shift sets and maintain cognitive strategies (i.e., WCST-CV4). Using this composite provided a measure of abilities that have varying degrees of verbal and non-verbal demands. As such, the findings can be considered robust and truly indicative of how higher order functions influence age-related memory change.

On the other hand, because the composite includes set shifting, sequencing, novel problem solving, abstraction, concept formation, and cognitive flexibility, what is lost is the unique contribution of the separate higher order abilities that fall under the umbrella of executive functioning in mediating the age-memory relationship. This is a common area of concern in neuropsychological assessment; whether a measure is sensitive enough to capture organic brain injury and specific enough to isolate the deficits to a certain cognitive domain. The present study provides a functional understanding of age-related memory change, in which the executive factor has a non-significant influence. Future studies examining executive functioning separately are needed to understand better the specific indirect effects of set shifting, sequencing, novel problem solving, abstraction, concept formation, and cognitive flexibility.

It was found in the present study that as individuals age their ability to plan, shift sets, use cognitive flexibility, and inhibit automatic processes decrease significantly. Understanding this relationship has been helpful for clinicians in accounting for changes in executive functioning that are associated with age. A derivative of having understood the direct relationship between age and certain cognitive abilities is normative data that is age corrected. Despite a declining trend in executive functioning with advanced age, when included as a predictor along with mediators that have been prominently studied in earlier research such as processing speed and working memory, performance on measures of executive functioning were not predictive of auditory memory.

As such, age related changes in auditory memory were not significantly mediated by age-related declines in executive functioning. The present results indicate that executive functioning becomes a less salient mechanism when included in a model with visual working memory and verbal intelligence, as the mediated effect of executive functioning was non-significant. These findings further reveal that set shifting, sequencing, novel problem solving, abstraction, concept formation, and cognitive flexibility are not necessarily a central determinant for how efficiently a person encodes sensory input or conducts other cognitive functions (i.e., recall or retrieval) as they age.

For the visual memory model, again, executive functioning decreased as age increased; however, executive abilities were not significantly related to visual memory. For researchers it is important to note that, albeit statistically non-significant, a positive (direct) trend was observed for the relationship between executive functioning and auditory memory while a negative (inverse) trend was observed between the visual memory and the executive control. Again, the findings revealed a possible distinction in the processes that underlie age-related memory change that are attributable to modal differences.

The present study aimed to expand on the cognitive aging literature by testing a mediation model that included previously ignored variables, as well as examining differences between the auditory and visual memory outcomes. The role of set shifting, cognitive flexibility, and executive control, proved to be non-significant, which was particularly true when the indirect effects of more prominent cognitive variables (i.e., verbal IQ and visual working memory) were accounted for. The results are significant to researchers and clinicians alike because they introduce a model of memory aging in which there are complex, underlying processes that mitigate and aggravate age-related memory change. Consequently, the present findings are not consistent with the executive decline hypothesis of cognitive aging. Moreover, these results highlight the utility of examining a more comprehensive mediation model in examining the complex processes and interplay of cognitive variables that underlie age-related memory change.

The prevalence of memory complaints and disorders among today's aging population is unprecedented. Clinicians and researchers have devoted significant resources to understanding ways to slow the process of memory decline both at the level of encoding and retrieval. The current research clarifies particular cognitive functions as mechanisms that underlie memory aging. By identifying targets for remediation such as visual working memory and verbal IQ, the present study informs cognitive remediation and other treatments aimed at slowing memory decline. With respect to reducing memory decline or restoring memory abilities, *Reasoning Remediation Training*, targets executive functioning as an underlying process that explains age-related memory decline. The training attempts to improve problem-solving, logical pattern recognition, and decision-making abilities, which are associated with everyday functioning and activities. Individuals are similarly trained in reasoning techniques, which are applied to everyday activities with similar reasoning demands.

In the ACTIVE study conducted by Ball and colleagues (2002), a large percentage of older adults who engaged in the training evidenced improved performance on executive functioning outcome measures; however, the enhanced performance did not generalize to cognitive abilities that were not directly targeted such as memory and speed of processing. Like many remediation techniques, the development of the program is based on single mediator studies and theories of cognitive aging that consider executive functioning in a vacuum.

The model of age-related memory decline tested in the current study found that regardless of the fact that frontal lobe functioning is impacted by increasing age, at the neurochemical and neuroanatomical level, the cognitive functions that are linked to the frontal and pre-frontal system do not explain age-related memory decline. Having controlled for the influence of other proposed targets of remediation, there was no evidence for executive functioning as a restorative mechanism. The findings of the present study indicate that the reason for the lack of restorative efficacy of executive functioning training is that executive functioning does not subserve age-related memory decline.

Furthermore, the present study informs interpretation and diagnosis within clinical neuropsychology. First the findings are consistent with common discourse that age-related decline in set shifting, cognitive flexibility, and executive control does occur in parallel with memory decline. Second, the findings indicate that the age-associated executive changes accounted for a non-significant amount of age-associated memory decline and therefore contribute minimally, if at all, to the processes that underlie memory aging. Third, in terms of functional changes in the brain and differential diagnosis in a clinical setting, these findings can be used to also understand normal aging vs. cortical vs. sub-cortical cognitive impairment. For instance, reduced cognitive speed and encoding are consistent with normal aging, while reduced attention, executive control, and speed are a hallmark of a sub-cortical dementing process. On the other hand, significant changes in retrieval and recognition memory, inhibition/executive control, and visual spatial skills are more closely related to cortical atrophy.

That the executive functioning composite was not found to be significant in mediating age-related changes in visual and auditory memory suggest that age-related frontal sub-cortical change (i.e., increased WMH and fewer axons) occurs in normal aging; however, the influence of executive functioning on memory is less profound than is seen in early sub-cortical dementing process. The present study highlights the importance of developing and testing a more comprehensive model of the mechanisms that underlie age-related memory change. By understanding the mechanisms that underlie normal cognitive aging, the field is better able to identify sub-cortical and cortical processes that may distinguish an early degenerative process from age-related change.

As has been shown with both processing speed and working memory, the mechanisms that underlie aging memory are more complex and not simply explained by changes in executive functioning. The present study has examined the cognitive processing and executive decline hypotheses, and has found that such theories of cognitive aging do not hold up within more inclusive mediation models. They are therefore of selective helpfulness for clinicians and researchers aiming to develop a functional model of memory aging. What remains to be understood is: (1) what variables are included in the mediation model that are rendering the commonly tested mediators (i.e., processing speed, capacity, and executive functioning) moot and (2) whether an inverse relationship exists in which the ability to encode, to store and to retrieve information is essential to higher order functioning. While the latter is beyond the scope of the present study, the following pages discuss the remaining two cognitive variables in terms of their salience to the model as well as the theoretical and clinical significance.

Hypothesis V

The next hypothesis under investigation asserted that the specific indirect effect of visual working memory on the relationship between age and auditory and visual episodic memory, controlling for the indirect effect of processing speed, executive functioning, working memory, and verbal IQ would be statistically significant at the .01 level. The findings did not support this hypothesis.

Instead, the results revealed visual working memory behaved differently in the relationship between age and auditory memory, than it did in the model containing visual memory as an outcome variable. In addition, differences between verbal and visual working memory emerged, which have relevance for researchers and scientists alike. Of greatest significance were the findings that after controlling for processing speed, executive functioning, verbal working memory, and verbal IQ, visual working memory was found to mediate age-related changes in visual memory significantly, while it did not significantly mediate the relationship between age and auditory memory. There are a number of implications for these findings, particularly for young old individuals.

First, the results indicate that the cognitive processing theory of cognitive aging does not hold up when included in a comprehensive mediation model. In an effort to examine the cognitive processing theory of age-related cognitive decline, the present study tested a model of mediation that included measures of both processing speed and capacity. The verbal working memory and visual working memory composite represented an individual's cognitive resources that are responsible for encoding and manipulating information into separate verbal and visuospatial storage subsystems. After examining the specific indirect effects of processing speed, as well as the specific contribution of a composite of verbal working memory, the results demonstrated that the cognitive processing theory, while informative in understanding age-related cognitive change, may be an oversimplified explanation of the mechanisms that underlie memory decline as individuals age, particularly for adults under the age of 70 years.

As noted above, this oversimplification has been the result of research that has examined processing speed and working memory in isolation of other cognitive factors. Therefore, an advantage of the present research was the inclusion of a number of cognitive variables that are sensitive to aging. In addition, because the present study aimed to parse out what cognitive functions are the most salient mediators of cognitive decline, the present study included two composites of working memory (i.e., verbal and visual). Playing a central role in humans' daily activities, visual working memory is the neural triage tool through which humans capture and store small amounts of information for immediate use and manipulation so as not to overwhelm more long-term stores with input that is time-limited with respect to its relevance. The capacity for encoding visual information and forming visual representations is influenced by how long one is exposed to the information and the perceptual complexity of the information. Often compared to the verbal working memory index for the WAIS-IV, the visual working memory tasks consist of novel complex tests that are considered to have a greater degree of difficulty.

The composite variable for visual working memory was comprised of the symbol span and spatial addition subtests from the WMS-IV. Both measures tap into an examinee's ability to hold visual spatial information about the location or details of the stimuli, mentally manipulate, and store information for the duration that it is needed to perform mental activities. However, these tasks are considered more complex and challenging than digit span tasks because they require more than attentional capacity to perform what is required successfully. While digit span backward and sequencing have been found to involve higher processing including the mental organization of information, again, the greater demand is on attention, numerical sequencing, and short-term storage. In healthy adults, the mental management of numbers or simple arithmetic operations achieves some level of being over-learned to the extent that it reduces the cognitive demand of such tasks as the arithmetic and digit span subtests.

With respect to task complexity, by including this visual working memory composite variable in the model, the current study provides empirical evidence for the variability in task complexity of working memory measures. For instance, age was significantly related to visual working memory and not verbal working memory indicating that the more difficult and involved tasks of working memory proved more sensitive to aging, particularly among adults under 70 years old.

The multiple mediation results did not fully support the hypothesized indirect effect, through the visual working memory. What emerged were differences based on the sensory modality of memory. Visual working memory after controlling for processing speed, verbal working memory, executive functioning, and verbal comprehension did not mediate age-related decline in auditory memory. Visual memory in contrast, was mediated by visual working memory after controlling for the other mediators in the model. The findings again raise the question of whether auditory and visual memory age along the same trajectory. While addressing this topic directly goes beyond the scope of the present analysis, the results do reveal that the underlying mechanisms that subserve age-related changes in verbal/auditory and visual/graphic memory are not uniform.

In the present analysis, a strong relationship was observed between visual working memory and visual memory. The relationship remained significant after controlling for variables that had demonstrated bivariate correlations with visual memory.

This strong correlation can likely be attributed to shared cognitive abilities that are required for successful completion of the working memory and recall memory tasks; including, encoding and remembering visual details, organizing spatial information and storing and manipulating data at different periods of time. It is also notable that the shared variance in tasks may be related to similar test construction such as the designs and spatial addition subtests both using the same memory grid. This contributes to an understanding of the present results.

Beyond implicating modal differences and highlighting the direct relationship between the mediator and visual memory outcome, these results help inform how the field conceptualizes the age-related processes of memory decline as something distinct from mild cognitive impairment or a dementing processes. While normal aging has been considered unique from mild cognitive impairment and dementia in that memory remains comparatively intact, the results provide evidence of early decline in visual memory most robustly as a function of decline in visual manipulation and integration. With respect to the interpretation of neuropsychological data into profiles, the findings demonstrate that having better working memory for visual information facilitates encoding of that information into long-term memory stores. In developing a comprehensive picture of patient neuropsychological data; a healthy older adult examinee would be expected to have similar scores on these indexes and similarly low scores would reflect both the presence of age-related memory decline and the mechanistic process responsible for measured difficulties in the long-term storage and retrieval of visual information. In contrast, discrepancies between the scores may point to an underlying neurological process that directly influences consolidation and hippocampal structure; thereby, ruling out an age related etiology for the memory difficulties.

On the other hand, there was an absence of a link between visual working memory and auditory memory. This suggests that modal differences once again emerge in normal cognitive aging where visual working memory does not readily accompany or underlie age-related auditory memory decline. This can be contrasted to Alzheimer's and amnesic mild cognitive impairment (MCI) patients for whom deficits in verbal and visual episodic memory are commonly found with little modal variability.

The results can also be interpreted in terms of the task demands. As noted earlier, auditory memory involves encoding, organization, consolidation, and storage of verbal information, which during testing is presented in either a list or contextual (i.e., story) format. The neuro-cognitive substrates necessary for verbal information retrieval following a delay involve temporal parietal structures, which while interconnected to neural networks that allow higher-level computation and manipulation of information, are not subserved by the same neural networks. While attention must occur for both memory and working memory to be optimal, the present results suggest that the changes in visual attention capacity in normal aging do not underlie changes in that ability to store and retrieve verbal information.

In addition, the visual working memory is believed to include both attention and executive functioning components (i.e., frontal sub-cortical) that are often impaired in individual's with vascular cognitive impairment. The deficit in memory retrieval is considered secondary to poor organization of information and the impaired ability to access spontaneously what was encoded characteristic of chronic ischemic white matter cognitive sequelae. However, the results of the present study distinguish age-related cognitive changes in list learning and contextual memory as they were not mediated by visual, or as noted above, auditory working memory.

As neuropsychology, particularly the rehabilitative application, continues to explore behavioral strategies and cognitive training for preserving memory and cognitive functions in aging, there is a need to have a functional understanding of the cognitive aging process. The clinical importance of the present results is that the study offers insight into the variable influence of visual working memory when considered in tandem with other variables. Pursuant to the findings, visual working memory is a relevant target for remediation; however, its influence in restoring or compensating for memory decline in normal aging adults will be greatest for visual memory.

Hypothesis VI

It was hypothesized that the specific indirect effect of the verbal IQ composite on the relationship between age and auditory and visual episodic memory, controlling for the indirect effect of processing speed, verbal working memory, executive functioning, and visual working memory would be statistically significant at the .01 level. The results supported this hypothesis.

The specific indirect effect of verbal IQ, which combines the relationship between age and verbal IQ (*a* path) with the predictive relationship between verbal IQ and auditory/visual memory (*b* path), was found to be significant at the .01 level. This means that verbal IQ significantly mediated the relationship between age and both visual and auditory memory. Even after controlling for the other mediators in the model (i.e., processing speed, verbal working memory, visual working memory, and executive functioning), verbal IQ maintained its significant indirect effect. The present findings can be interpreted from a number of perspectives including: (1) verbal IQ serving as a compensatory variable; (2) the lack of modal differences in verbal IQ’s indirect effect on age-related visual and auditory memory change; and (3) verbal IQ as a proxy of cognitive reserve.

In the first hypothesis, the *ab* pathways of the various mediators were found to be inconsistent - revealing that some mediators promoted age-related decreases in memory while others promoted age related increases in memory. The emergence of opposing mediators demonstrated that the processes underlying age-related memory change were both mediating (aggravating) and compensatory (mitigating). Within the comprehensive model tested in this study, verbal IQ promoted an age-related increase rather than decrease in memory. Therefore, verbal IQ can be said to have had a significant compensatory effect on age-related auditory and visual memory change. The findings provide support that verbal abilities, which continue to be acquired throughout adulthood, facilitate better encoding and retrieval of information, even into later life.

The compensatory effect of verbal IQ on age related auditory memory changes can be understood via the overt verbal demand of the auditory memory composite. This outcome variable was measured by an individual’s ability to immediately recall stories and remember them after a 30-second delay, as well as to learn, to store, and to retrieve strings of word-pairs immediately and following a 30-minute delay. The present study found that such auditory memory abilities do decline with age. However, verbal IQ was found to intervene on this relationship in such a way that it resulted in an increase rather than a decrease in auditory memory. When considered in terms of neuropsychological performance, the findings highlight that as individuals’ age, they acquire verbal abilities and knowledge over time. These increases in verbal IQ essentially enhance an individual's ability to meet the demands of auditory memory tasks. Such demands include the ability to comprehend directions that are read to the individual without visual stimuli, to encode verbal information of the stories and to use verbal strategies to create associations between word pairs that were often unrelated. Translated to activities of daily functioning, the findings implicate verbal IQ as subserving, to some extent, the efficiency with which verbal information is encoded, organized, and stored. Furthermore, changes in the retrievability of the stored information, as one ages, appear to have some dependence on the ability to listen and to understand the meaning of spoken information; to understand the relationships between language concepts and to analyze and solve language based literary, interpersonal, or logical problems.

The compensatory effect of verbal IQ on age-related visual memory change can be understood by considering the visual memory outcome variable. This composite captured an individual's ability to remember geometrical designs and draw them immediately and following a 30-minute delay, as well as place the correct designs in the correct location on a grid, following the visual presentation of a series of pages with designs arranged in grid. For such tasks, the individual was required to transform information into mental representations that were accessible for short-term retrieval and that could be consolidated into long-term memory stores. The findings of the present study are relevant because they implicate verbal IQ in supporting an individual's ability to comprehend verbally presented instructions that prepare the examinee for the demands of the visual memory task, as one ages. Moreover, these findings support the role of verbal mediation of visual information throughout adulthood. Moreover, verbal IQ increases ones' ability to create mental representations of visual stimuli – resulting in better organizing, storage, and recall of the material.

As a compensatory variable, verbal IQ also serves as an opposing effect among the other mediators included in the model. Whereas other mediators proposed in this study contributed to age-related decline in memory performance, verbal IQ exerted its influence on the relationship between age and memory by supporting better functioning. This means that, because of higher verbal abilities, an individual's auditory and visual memory becomes less sensitive to age-related declines in processing speed, executive functioning, and visual working memory, as they age. The findings are important because they reveal the presence of a compensatory influence of verbal IQ among the complex processes that underlie changes in memory across the adult spectrum. The findings also appear to be the first to have uncovered the suppression or compensatory effect of verbal IQ, which appears to be central in developing a functional understanding of the complex cognitive processes that underlie memory aging.

Another way to understand the present findings is through the lack of modal differences in verbal IQ's indirect effect on age-related visual and auditory memory change. Out of the five mediators under study, verbal IQ was the only variable that significantly mediated age-related changes in both auditory and visual modes of memory. In the investigation of the specific indirect effect of the other four mediators, differences emerged in the behavior of the mediators based on the modality of memory. However, for verbal IQ, the results revealed a significant compensatory influence on age-related memory change regardless of the sensory modality of memory. While it is beyond the scope of the present study to examine whether the indirect effect of verbal IQ on auditory memory was statistically different than indirect effect of verbal IQ on visual memory, the present results do suggest that verbal IQ underserved both modalities of memory at a statistically significant level.

For clinicians, the results implicate the involvement of verbal IQ within the separate systems of visual and auditory memory by demonstrating a shared dependence on verbal IQ. As one ages, being able to verbally label figures and verbally describe spatial information contributes to efficient creation of mental representation, which directly enhances visual memory storage. In the same way, being able to understand and define words, tag and organize language, and comprehend instructions contributes to better auditory memory. For neuropsychological assessment, the results highlight the importance of assessing language, comprehension and vocabulary as a means to better understand and functionally interpret memory performance, particularly within an aging population. When assessing verbal IQ, lower scores should be taken into consideration as part of the interpretation of visual and verbal memory performance. Particularly when ruling out dementia and mild cognitive decline in older adults, individuals may exhibit fewer declines in both visual and verbal memory than would be expected for their age because of their increased verbal abilities. Additionally, in the case of a re-evaluation, patients may demonstrate improvement in their memory performance over time, which can to some extent, be functionally understood in terms of their acquisition of verbal knowledge as they have aged.

The findings also evoke a discussion of cognitive reserve, which has become a salient topic for clinicians and researchers, particularly in evaluating and appreciating the neurocognitive sequelae of brain injury, degenerative diseases, and aging. The present examination provides evidence for the role of cognitive reserve in normal aging via the proxy, verbal IQ. Domains or “proxies” of cognitive reserve have included IQ, achievement, occupation, and social activities. Cognitive reserve refers to the degree of flexibly and efficiency one has in using available brain resources thereby preserving functioning despite the presence of brain degeneration or injury (Sole-Padulles et al., 2009). In the present cross-sectional analysis, as individuals aged, they demonstrated greater verbal IQ - suggesting that even individuals in their fifty’s, sixty’s and seventy’s are still acquiring verbal IQ. As verbal IQ was found to support better memory performance as individuals aged, the findings indicate that verbal IQ is a brain resource that promotes efficiency and flexibility in carrying out auditory and visual memory functions, regardless of the level of age-related cognitive degradation.

In the area of cognitive remediation and rehabilitation, the results have clinical utility by revealing that verbal IQ may be an appropriate target for improving age-related decline in memory. While the present findings cannot be generalized to impaired populations, this research demonstrates the necessity of identifying the mechanistic processes of normal adult age-related memory change. As such, the most likely contribution of the present study is to inspire further research on the clinical viability of verbal IQ as a target for remediation in memory aging, as well as resource for preserving memory functioning into late life.

Contrasting the Specific Indirect Effects

Hypothesis VII

Using pairwise comparisons to contrast the strength of the proposed mediators, it was purported, that the magnitude of the specific indirect effects of processing speed, verbal working memory, executive functioning, visual working memory, and verbal IQ were not of equal size and would therefore be different from each other at the .01 significance level. The results of the present analysis did not support the hypothesis, as a number of non-significant contrasts emerged.

Only the contrast between the mediated effect of verbal IQ and working memory were found to be significant for the auditory memory outcome. For the visual memory outcome, only four out of the ten contrasts were found to be significant: (1) verbal IQ vs. processing speed, (2) visual working memory vs. verbal IQ, (3) visual working memory vs. verbal working memory, and (4) visual working memory vs. executive functioning. These findings can be interpreted in terms of the contrasts that were indistinguishable, as well as the contrasts that were found to be meaningfully distinct.

In Hypotheses II – VI, the specific indirect effect of age through processing speed, verbal working memory, executive functioning, visual working memory, and verbal IQ were examined separately. These earlier findings highlighted which variables, after controlling for the other mediators in the model were the most salient cognitive mechanisms underlying memory aging. However, the earlier hypotheses did not address whether the specific indirect effect of one mediator was larger or smaller when compared to another. In the evaluation of a rehabilitation program or understanding neuropsychological data, researchers and clinicians may often test the indirect effects of latent variable and examine which mediated effect is largest. For example, researchers and clinicians may consider whether, as individuals age, processing speed training or a vocabulary/reading exercise has a larger mediated effect on preserving memory. Therefore, the methodological implications of generating effect sizes are that they facilitate a discussion of the magnitude of each mediator on memory aging. The effect size results analysis also translate the present findings into a functional discussion of each mediator based on the amount of change in the outcome variable (i.e., auditory or visual memory) that can be attributed to the specific indirect effect of the mediator, given a single standard deviation change in the independent variable (i.e., age). Most importantly, the contrast findings show whether the specific indirect effect through one mediator is meaningfully larger than the specific indirect effect through another thereby allowing for the comparison of the different theories of cognitive aging within the model.

For the auditory memory outcome, a number of non-significant contrasts emerged. There was no appreciable difference in the magnitude of verbal IQ's mediated effect, when compared separately to that of processing speed, visual working memory, and executive functioning. Because zero is contained in the confidence interval for these contrasts (i.e., verbal IQ vs. processing speed; verbal IQ vs. visual working memory and verbal IQ vs. executive functioning), the two indirect effects cannot be distinguished in terms of magnitude, despite the fact that verbal IQ's mediated effect on auditory memory was significant and the others were not. This apparent paradox is likely because the specific indirect effect of verbal IQ is relatively small in magnitude. The present results demonstrated that the amount of change (i.e., increase or decrease) in auditory memory performance attributable to verbal knowledge as individuals age, was not significantly larger than the amount of change ascribed to speed of processing, attentional capacity for visual information, set shifting, cognitive flexibility, or concept formation.

The magnitude of the specific indirect effect of processing speed on auditory memory aging, when compared pairwise to verbal working memory, visual working memory, and executive functioning, did not significantly differ. These findings indicate that for one standard deviation change in age, the amount of change (i.e., increase or decrease) in auditory memory performance attributable to processing speed was not significantly different from the amount of change ascribed to attentional capacity for verbal or visual information, set shifting, cognitive flexibility, or concept formation. This finding is not surprising considering that each of these specific indirect effects, when tested in hypotheses II, III, IV, and V were found to be non-significant.

When visual working memory was compared pairwise to verbal working memory, and executive functioning, there were no significant differences in the magnitudes of their mediated effects. The findings again reveal that for one standard deviation change in age, the amount of change (i.e., increase or decline) in auditory memory performance attributable to visual working memory was not significantly larger than the amount of change ascribed to attentional capacity for verbal information, set shifting, cognitive flexibility, or concept formation. The contrast findings demonstrate that these indirect effects were comparably small.

For visual memory, a number of non-significant contrasts emerged as well. There was no appreciable difference in the magnitude of verbal IQ's indirect effect, when separately compared to that of verbal working memory and executive functioning. Again, the two indirect effects in each contrast (i.e., verbal IQ vs. working memory and verbal IQ vs. executive functioning) cannot be distinguished in terms of magnitude, despite the fact that the mediated effect of verbal IQ was significant while the others were not (see hypothesis III, IV and VI). The amount of change (i.e., increase or decrease) in visual memory performance that is attributable to verbal knowledge as one ages, was not significantly larger than the amount of change ascribed to attentional capacity for verbal information, set shifting, cognitive flexibility, or concept formation.

Processing speed, when contrasted with verbal working memory, executive functioning, and visual working memory, contributed to similar rates of change in visual memory, as individuals' age. In terms of comparing the various theories of aging, this finding demonstrates that the amount of change (i.e., increase or decrease) in visual memory performance that can be explained by the Processing Speed Hypothesis is no greater than the amount of change that can be explained by the Executive Decline Hypothesis or theories that purport working memory as being salient. In the head to head comparison of the different magnitudes (i.e., processing speed vs. verbal working memory; processing speed vs. executive functioning and processing speed vs. visual working memory), no single mediator emerged as superior to the other.

For clinicians and rehabilitation psychologists, these reported effect sizes provide estimates for how much change in visual memory can be expected when targeting a particular mediator. Moreover, the contrast results demonstrate that many of the mediators included in the model are comparable targets for remediation because when compared to each other, many resulted in a standard deviation change in memory that was statistically similar to each other. Among the mediators included in the model for visual memory outcome, very few of them stand out in terms of the magnitude of their specific indirect effect and therefore do not stand out as being particularly superior targets for remediation.

On the other hand, select contrasts did emerge as significant in both the auditory and visual memory model - revealing that select cognitive abilities do stand out from others in terms of the magnitude of their specific indirect effect on age-related memory change. For the auditory memory outcome, verbal IQ when contrasted to verbal working memory was found to have a significantly larger mediated effect. Therefore, verbal knowledge can be said to meaningfully account for a larger amount of age-related auditory memory change than does the capacity to attend to and manipulate verbal information.

Caution was used when interpreting these findings, particularly in the context of nine out of ten non-significant contrasts for which there was appreciable difference in verbal IQ, processing speed, executive functioning, and visual working memory. For clinicians, this particular finding provides support for verbal IQ as being equally relevant to the discussion of age-related memory changes as other cognitive abilities because it hangs together with other mediators in the model in terms of its magnitude. Moreover, the ability to listen and to understand the meaning of written or spoken information; to understand the relationships between language concepts; and to analyze and to solve language based literary, interpersonal, or logical problems has a larger influence on age-related memory change than does an individual's capacity for attention, mental manipulation, and short-term storage of verbal information. According to the results, verbal IQ is a more salient factor than short-term storage and manipulation of verbal information in facilitating the organization, long-term storage, and retrieval of auditory information throughout adulthood.

There were also select significant contrasts for the visual memory outcome. The magnitude of verbal IQ's mediated effect was found to be significantly larger than that of processing speed. As such, the amount of change in visual memory performance that was attributable to verbal knowledge was distinctly larger than the amount of change ascribed to the speed at which information was processed. This is particularly relevant for determining whether any one “brain training” technique is superior to another. According to these findings, cognitive remediation and rehabilitation strategies, which aim to increase verbal knowledge vis-à-vis preserving one’s ability to construct mental representations of visual information efficiently, will likely inspire greater positive change in retrieval of the stored visual information than will strategies that aim to increase the speed at which visual information can be encoded.

When compared to executive functioning, the specific indirect effect of visual working memory was significantly larger in magnitude. These findings indicate that for one standard deviation change in age, the amount of change (i.e., decrease) in auditory memory performance attributable to attentional capacity for visual information was significantly larger than the amount of change ascribed to, set shifting, cognitive flexibility, or concept formation. This is not surprising considering that the specific indirect effect of visual working memory was found to be significant in Hypothesis V while the mediated effect of executive functioning was non-significant (see Hypothesis IV). The findings also suggest that in terms of targets for cognitive remediation of age-related visual memory decline, visual working memory is superior to that of executive functioning.

In addition, visual working memory, when contrasted with verbal working memory, contributed to significantly larger rates of change in visual encoding, storage, and retrieval, as individuals’ age. This is significant in terms the modal differences that this study aimed to uncover. It was found earlier that, as individuals age, visual and not verbal working memory significantly mediated visual episodic memory. The present contrast findings reveal this modal discrepancy to be statistically meaningful, in that the amount of change (i.e., decrease) in visual memory performance attributable to attentional capacity for visual information is significantly larger than the amount of change ascribed to verbal processing capacity. For clinicians, the findings demonstrate that cognitive remediation and rehabilitation strategies that aim to preserve capacity for visual processing and mental manipulation are likely superior to those directed at verbal processing capacity. These results are also relevant for the practice of neuropsychological assessment, as they provide support for visual and verbal working memory being two very distinct systems that differentially influence other cognitive functions. When conducting evaluations in which age-related cognitive decline is being distinguished from pre-dementia, it may contribute to one's understanding of the data and the patient to include measures of both visual and verbal working memory.

Finally, the contrasts examined the mediated effects of verbal IQ vs. visual working memory. Because zero was not contained in the confidence interval for this contrast, the two indirect effects were distinguishable in terms of magnitude, despite the fact that both visual working memory and verbal IQ significantly mediated the relationship between age and visual episodic memory. These results serve as evidence that visual working memory is a highly salient cognitive factor influencing change in visual memory as we age. Operationally, visual working memory is the collection of mechanisms (i.e., the capacity) for rapidly organizing and maintaining visual information, while inhibiting immaterial data. Among aging adults, as these capacities attenuate, individuals become less adept at encoding and retrieving visual information. As such, the concerted processes of capturing relevant information while suppressing irrelevant information had a larger mediating influence on age-related decline in visual memory than did the compensatory effect of verbal knowledge. Despite the compensatory nature of verbal IQ, which was noted earlier, as individuals age visual working memory continues to intervene in the ability to retrieve visual information both initially and after a delay. This again indicates that age-related decline in visual working memory (i.e., attention, inhibition, and mental organization) is heavily responsible for the challenges that adults face in attending, organizing into storage, and in retrieving visual information.

For the field of rehabilitation, the present results contribute to the field's understanding of what cognitive factors serve as salient targets for remediation. When compared to attention and mental manipulation of visual information, verbal IQ had a measurably smaller influence on visual memory – making visual working memory a more salient target. Therefore, programs that help counter age-related visual memory decline through compensatory-based techniques may benefit from "new learning" techniques such as spatial additional over tasks that are found to promote the acquisition of verbal knowledge.

Conclusion

The primary goal of this study was to establish whether age-related differences in episodic memory were explained by age-related declines in cognitive abilities that are considered more fundamental than episodic memory in a hierarchy of cognitive functions. The hierarchically fundamental processes that were thought to have a broad influence on cognitive functioning included processing speed, verbal working memory, executive functioning, visual working memory, and verbal IQ. Taken together, the results of this multi-hypothesis investigation addressed this question and introduced a more comprehensive model of the processes that underlie memory aging. Of note, the current study addressed a number of the challenges that have faced earlier studies in an effort to develop a more robust model for memory aging.

First, the current research examined encoding and free recall (i.e., episodic memory) as two separate modal systems (i.e., visual and auditory). By doing so, the present study was able to directly and inductively identify modal differences in memory aging via the different processes that underlie age-related memory changes. Secondly, the study's design included variables that have not been discussed or incorporated into a multiple mediation model of age-related memory change. For example, verbal IQ, verbal working memory, and visual working memory were each examined for their combined and specific mediating effect, along with more commonly discussed factors (e.g., processing speed and executive functioning). Statically, the present analysis used bootstrapping to address parametric and correlational limitations of earlier used methods and generated information about magnitude of the five specific indirect effects. Such effect size and contrast analyses facilitate a discussion about how much age-related change in memory is ascribed to each mediator and whether that magnitude is distinctly larger than the other mediated effects. Lastly, because the sample included adults ages 16-70, the findings offer a picture of age-related memory change that is applicable to lifespan neuropsychology.

In summary, both visual and auditory memory were found to be sensitive to aging, but not equally so. From the perspective of variance accounted for, the regression coefficients for the direct effect of age on visual memory were larger than that of auditory memory – meaning that increased age was responsible for greater declines in visual memory than in auditory memory within the same sample of non-demented individuals.

While there is some consensus in the literature that both auditory and visual memory decline with increasing age (Lezak et al., 2004), that consensus does not extend to the body of literature regarding whether the rates of decline vary between the different domains of memory as we age. A large body of empirical research has found that both forms of memory have similar rates of decline (Kemps & Newson, 2006; Park et al., 2002; Salthouse, 1995). On the other hand, Hale et al. (2011) most recently examined visual and verbal episodic and working memory among 388 adults - ranging in age from 20 to 89 years of age and reported differences in the rates of decline for visual versus verbal memory tasks. The researchers administered novel verbal and visual-graphic material of varying difficulty, the less complex of which required that the examinee recall verbal or visual items on a screen immediately. The visual short-term memory tasks showed greater rates of decline that did verbal tasks.

A common limitation of earlier research on memory aging, as well as studies that have examined the variation in the rates of age-related decline in auditory and visual memory, centers on the type of assessments used. Frequently, verbal information is presented visually on a screen to assess verbal memory (Hale, Myerson, & Wagstaff, 1987; Lawrence, Myerson, & Hale, 1998). By presenting both verbal and spatial information in a visual format, researchers have not created a true measure of verbal-auditory memory. This design component explains, to an extent, the conflicting results that have emerged from earlier research, as well as researchers' inability to establish whether auditory and visual memory decline at different rates as individuals age.

The present study used a pure measure of verbal-auditory and visual-graphic memory to improve upon this limitation. By examining encoding and free recall (i.e., episodic memory) as two separate modal systems (i.e., visual and auditory), the present study was able to directly and inductively identify modal differences in memory specifically through an examination of the mechanisms that underlie age-related memory changes. The results have empirical and clinical significance as they confirm that visual memory is more sensitive to age than auditory memory (Jenkins, Myersons, Joerding, & Hale, 2000; see also Head, Rodrique, Kennedy, & Raz, 2008; Park et al., 1996).

Consistent with earlier research (Salthouse, 1985, 1996; Verhaeghen & Salthouse, 1997; Zacks & Hasher, 1994), the present findings also reveal that age-related decline, or more generally, changes in visual memory are to some extent the manifestation of age-related changes in underlying processes, including processing speed, processing capacity, attention, executive functioning, and verbal IQ. However, the results indicate that when the processing speed, verbal working memory, executive functioning, visual working memory, and verbal IQ were examined for their total mediated effect, the model was only found to be significant for the visual memory outcome. While long-term memory for visual spatial and verbal information in older adults is an ever-growing topic of study, evidence does exist toward a more precipitous decline, with age, in visual spatial processes compared with verbal processes (Jenkins, Myerson, Joerding, & Hale, 2000; Myerson, Hale, Rhee, & Jenkins, 1999). There is also evidence for equivalent declines in the auditory and visual memory domains (Reuter-Lorenz, 2000). The present study directly highlights changes in cognitive functions across the adult age range for both visual spatial and verbal domains. Such differences between visual and auditory memory aging occur even at the level of the different mechanisms that underlie age-related memory change.

Separately, the mediated effects of processing speed, verbal working memory and executive functioning were non-significant, after controlling for the other variables in the model. For researchers and clinicians, the present findings identify the complexities and nuances of age-related memory decline and inspire a paradigm shift, particularly as it is commonly held that memory declines as individuals age in some part due to age-related declines in processing speed and capacity (Salthouse, 1996) and executive functioning (Luszcz & Bryan, 1999).

Referred to as the cognitive processing model for age-related cognitive decline, this early theory of age-related cognitive decline proposed two mechanisms of mediation including: (1) the rate at which information can be encoded, stored, and used: and (2) the capacity for tracking and manipulating verbal and spatial information. According to Salthouse (1996), age-related changes in cognitive functioning are significantly influenced by how quickly individuals can think. A number of studies have examined the existence of an indirect effect of processing speed on age-related declines in performance on memory tasks (Salthouse, 1996) and fluid intelligence (Salthouse, 2000). Employing structural equation modeling, Hertzog, Dixon, Hultsch, and MacDonald (2003), found that changes in speed and working memory predicted age-related changes in episodic memory.

In addition, it is traditionally held that working memory capacity is susceptible to age because of the attenuation in adults' resources for manipulating information over time (Craik, 1986). Working memory models have asserted that as individuals age they become deficient at inhibiting tangential or extraneous information, discarding irrelevant input, and restraining preservative or inappropriate responses (Hasher & Zacks, 1988). It is through this breakdown in attention and short-term storage of information that researchers suggest the working memory system does not allow the individual to capture needed information or to perform the proper goal directed responses as we age.

Executive functioning has also been theorized to be informative regarding differences in memory abilities as individuals age (Dempster, 1992). The executive decline hypothesis asserts that as individuals age the prefrontal lobes suffer more rapid and progressive changes. Such age-related atrophy in the frontal cortex results in attenuated functioning of higher order or executive abilities, thereby producing a decline in related areas of functioning such as memory, which are believe to be subserved by executive abilities. A number of studies have found executive functioning to be a significant mediator of the relationship between age and memory. In one such study, Crawford and colleagues (2000) examined age-related changes in executive functioning among individuals ages 18 to 75 years and individuals 60 to 89 years. He found that executive functioning accounted for a significant amount of the age-associated variance in measures of memory for both age groups. Early studies that demonstrate executive functioning as a mediator have been informative when considering executive functions in isolation. However, the comprehensive scope of the present investigation helps clinicians and researchers appreciate the role of executive functioning in the context of other salient mediators. Crawford et al., (2000) examined processing speed and executive functioning together in their mediation model. The indirect effect of executive functioning was non-significant after controlling for processing speed. Similarly, other studies have examined executive control and processing speed as mediators of memory and have found that executive functioning had a smaller mediating effect when taking into account cognitive speed (Bunce & Macready, 2005).

However, when comparing these theories of aging via the pairwise contrasts, they were found to be equivalent and each was found to be a non-significant mediator of age-related memory change. The specific indirect effect and contrast analyses revealed other cognitive mediators in the model to be more salient in developing a functional understanding of memory aging. The present study further revealed a more complex interplay among the mediating variables in which verbal IQ was found to be the only variable to intervene significantly on the relationship between age and auditory memory, after controlling for the other mediators in the model. For the relationship between age and visual memory, both verbal IQ and visual working memory were found to be significant.

Additionally, pairwise comparisons between the magnitudes of the different specific indirect effect revealed that certain mediators had a larger indirect effect than did others. The mediated effect verbal IQ was found to be distinguishably larger than verbal working memory for the auditory memory outcome. Visual working memory, on the others stood out from verbal working memory, executive functioning, and verbal IQ in terms of its mediated effect on visual memory change. These findings highlight verbal IQ as a particularly understudied yet relevant factor influencing memory aging.

There is currently a paucity of research establishing age-related changes in verbal IQ because, most traditionally, verbal IQ was believed to have a stable trajectory throughout adult hood and to be resilient to neurological conditions. Verbal IQ has been found to be less susceptible to decline in Alzheimer's disease (Grober, Hall, Lipton, Xonderman, Resnick, & Kawas, 2008). In brain injury populations, verbal abilities often show less initial impairment and demonstrate faster recovery toward premorbid levels that non-verbal abilities. Across the human developmental life span, verbal IQ follows a curvilinear course from childhood to death, in which verbal abilities increase rapidly between childhood and early adolescence, peak between late adolescence and early adulthood, plateau throughout adult hood and begin to decline around 80 years of age (Lezak, 2004). As such, verbal IQ has been discarded as a mechanism for age-related cognitive change (Verhaeghen, 2003). The present study found increases in verbal ability across the life span that compensated for age-related memory decline. This discrepancy may be due to earlier studies including a large number of adults in the eighth, ninth and 10th decade and severe decline occurs at these older ages (ages that are not represented in the present studies sample) due to limited access to elderly participants and the goal of examining the linear relationship of verbal IQ. Nevertheless, the study establishes that verbal IQ likely improves with age, before a certain point (i.e., 80 years old), and plays a role in memory aging across the adult lifespan.

Moreover, the contrast results support working memory as being separate visual and verbal systems that differ with respect to their sensitivity to aging and their influence on age-related memory decline. The present study included two composites of working memory because it has been found in the literature, that verbal and spatial working memory are organized asymmetrically (Reuter-Lorenz et al., 2000). Verbal storage tasks have been associated predominantly with activation of the left-hemisphere near Broca's area, which plays a role in the rehearsal of verbal information through which it is retained short-term. During brief storage of visual spatial information, activation and perfusion occurs predominately in the right hemisphere, and particularly in areas analogous to brain regions that are activated during verbal storage (Jonides et al., 1993). Appreciating the relative lateralization of working memory for visual and verbal information, it is neurobiologically understandable that it would influence visual and auditory encoding and recall differently.

From the contrast analysis, visual working memory was found to have a larger specific indirect effect on age-related visual episodic memory decline than did verbal working memory. The results demonstrate domain specific perception and memory. This is consistent with previous research that has suggested a hierarchical processing and organization of information beginning with striate cortex, which outputs to extrastriate regions, which in turn outputs to temporal cortex (ventral stream) or parietal cortex (dorsal stream), both of which ultimately converge on the hippocampus (Felleman & Van Essen, 1991). Possibly, the results are representative of how visual working memory and visual episodic memory share similar right hemisphere neural pathways that do not overlap with verbal processing.

With respect to task complexity, by including this visual working memory composite variable in the model, the current study offers empirical support that more difficult and involved tasks of working memory are more sensitive to aging, particularly among adults younger than 70 years old (Bopp & Verhaeghen, 2005; Zacks, Hasher, & Li, 2000). The composite variable for visual working memory was comprised of the symbol span and spatial addition subtests from the WMS-IV. Both measures tap into an examinee's ability to hold visual spatial information about the location or details of the stimuli, and to mentally manipulate and store information for the duration that it is needed to perform mental activities. However, these tasks are considered more complex and challenging than digit span tasks because of their novel nature and greater demand on higher cognitive functions to perform what is required successfully (Myerson, Emery, White, & Hale, 2003). While digit span backward and sequencing have been found to involve mental organization of information, the greater demand is on attention, numerical sequencing, and short-term storage. In healthy adults, the mental management of numbers or simple arithmetic operations achieves some level of being over-learned to the extent that it reduces that demands of tasks such as arithmetic and digit span. The contrast analyses further support that complex working memory tasks are central to an understanding of age-related memory decline while less complex tasks have a much lesser effect.

A final interesting finding was the continued direct effect of age on episodic memory that remained after the specific effects of the cognitive mediators were taken into account. The effect of age on episodic visual and auditory memory was not completely mediated by the variables in the model. This is consistent with most multiple mediator studies that have examined cognitive mechanism of memory aging (Salthouse, 1996; Salthouse, 2000; Hertzog et al., 2003). However, other studies that have included non-cognitive factors as well as cognitive mediators have put forth more holistic models of age-related memory change. While one study did find that the inclusion of regional brain volumes, processing speed and components of executive functions sufficiently explained the age memory relationship (Head, Rodrique, Kennedy, & Raz, 2008), very few studies have examined a more holistic set of mediating variables. Perhaps this is the next area in developing a more functional understanding memory aging.

Limitations

Multiple mediation analyses are becoming more frequently utilized as a means to understand the mechanisms that influence or explain the direct relationship between any two factors. The question of why memory declines with age has evolved into a discussion about how and through what age-related changes does memory degrade over time. To date there have been many studies investigating cognitive aging; however, few, if any, have looked at the difference in sensory modalities of memory as we age. Furthermore, verbal IQ has been overlooked in the literature as a potentially influencing factor, particularly in those studies that have been circumscribed to older adult samples and negative effects of aging on cognition. While the present study was designed to complement and expand on previous research, there are a number of limitations that must be discussed, which are directly related to these design strengths.

There are characteristics of the sample that influence and potentially limit the generalizabity of the findings. In the present study, the sample was comprised of a high proportion of graduate level student and professionals. Due to this high education sample, the findings of the present study, may not necessarily capture or reflect the results that would be derived in a more culturally diverse or lower education sample. Appreciating the relationship between education level and cognitive ability, it was expected that the individuals in the sample would demonstrate higher than average performance on the processing speed, verbal working memory, executive functioning, and visual working memory tasks. This was supported by the skew and kurtosis of the data. Subsequently, this higher level of functioning provided a context in which the results were interpreted an understood. Caution was used particularly because the results may be less applicable to samples comprised of individuals with less education.

Additionally, it was identified in a previous study that education had a moderating influence over the course of life-span changes in cognition, particularly among individuals with a low level of education, for which older individuals with more education demonstrated better cognitive performance compared to low education younger adults (Ardila, Ostrosky-Solis, Rosselli, & Gomez, 2000). Without an education correction or analysis of education as a potential confound, the present results require caution when being applied to other populations that have been found to have lower educational attainment. However, the relationship between age-related cognitive decline and education appears to differ depending on the cognitive domain. This is likely a separate investigation on its own. As such, an examination of the influence of education on episodic memory, processing speed, verbal working memory, executive decline and visual working memory, are beyond the scope of the present study. However, by conducting this multiple mediation analysis, the present study identifies a new area for follow-up, which is examining whether education moderates the mediated effect of age through the specific indirect effects of verbal IQ and visual working memory that have been established in this study.

A second limitation was that the sample consisted of adults ages 16 to 70 years and did not include adults on the older end of the spectrum. While it is important to examine the cognitive mediators that underlie memory performance across the developmental lifespan in order to appreciate variations in the mediated effect as a function of age group, the limited age range of the sample restricts the applicability of the results to individuals older than 70 years of age. This is of particular importance in that it has been established in the literature that cognitive functioning shows a more rapid rate of decline in the eighth decade (Lezak, 2004; Salthouse, 2009). Moreover, caution must be used when applying the findings to the remediation or cognitive rehabilitation of memory for individuals of a more advanced age. Nevertheless, the results are very relevant to the middle and older adult population for which age-related cognitive decline is becoming a very salient concern. The sample was also found to have a large representation of individuals 21-30 years of age, which limited the generalizablity of the findings to age groups not included (i.e., > 70 years old). However, it has been found in the research that certain aspects of cognition among normal adults, with high school level or greater education begin to decline as early as the late second and early third decade (Salthouse, 2009). As such, studies that only capture cognitive aging in the elderly population may not offer as rich an understanding of the maturation of cognitive processes as the present analysis.

Additionally, all participants in the study denied a history of current or historical neurologic or psychiatric impairment. By not including clinical groups (i.e., participants with mild cognitive impairment, ADHD, TBI, early Alzheimer's, vascular, Parkinson's and other dementias) the results do not offer any insights regarding the differences in mechanisms that underlie memory change that occurs as a result of the interaction between age and the neurocognitive disease process. The present results are most generalizable to a normal rather than a clinical population. However, the results may be helpful in developing functional methods to assess and to understand at-risk populations (i.e., the elderly, pre-dementia and patients with history of traumatic brain injury, etc.), as well as interventions to improve memory fitness and to compensate for degradation secondary to aging or a dementing process.

While the present analysis incorporated a comprehensive set of theory-driven mediators, the scope of the analysis was circumscribed to cognitive mediators of age-related memory decline. This study therefore did not consider non-cognitive mediators (i.e., occupation, social support, education, brain volume, perfusion, glucose metabolism, exercise, or marital status), which potentially influence the age-memory relationship. While this limitation does not compromise the empirical and clinical relevance of the present study, the findings highlight that even after accounting for the five mediators, age-related variance in auditory and visual memory remained, which was unexplained by the cognitive factors that were included in the model. Taking a more holistic approach has proven useful in explaining the clinical presentations and neuropsychological deficits, and it may prove helpful to applying this to understanding the impact of physiological, educational, and lifestyle factors on age-related maturation of memory. While this may be a new area of research, the present study offers little to this discussion due to its focus on cognitive mediators. On the other hand, a strength of the present analysis is that it investigated a comprehensive set of mediators, including cognitive domains that have yet to be examined together. This study makes evident that research on cognitive aging must expand beyond cognitive mediators, as there are likely mediating variables that have yet to be accounted for.

With respect to methodological constraints, the present study employed z-score composites comprised of adequately valid and reliable subtests that were re-standardized and averaged to obtain a single domain representing the cognitive construct (i.e., auditory memory was a mean of the z-scores for Logical Memory I & II and Verbal Paired Associated I & II). For more information about this method, see Chapter III. While this method of measuring unobservable attributes such as memory or executive functioning is favorable to using raw scores (Salthouse, 1991), it does not allow for an examination of the indirect effects of the individuals subtests that comprise the composite. When any composite is created from multiple tests, there is a concern of blurring tests that are considered to reflect an underlying construct with measures that are a combination of tasks that when fitted together reflect a single construct. Particularly for umbrella constructs such as “executive functioning”, which represents problem-solving, abstract reasoning, concept formation and planning, or “memory”, which includes the process of encoding, organization, tagging/making association, retrieval and recognition; consolidating tests that may tap one, some, or all of these variables reduces the richness and assumes shared variance among the tests in the composite. The present study attempted to reduce this limiting factor by having composites that were comprised of correlated measures or tests that are commonly incorporated into indices; however, an alternative methodology may have offered more in appreciating the mediated effect at the level of the latent factor, as well as the composite.

It is important to also mention that the auditory and visual memory composite variables included both immediate and delayed recall subtests, which may have influenced the results, considering that immediate memory subtests have a greater attention, encoding, and organization demand while delayed subtests reflect one’s ability to store and to retrieve information that was previously presented. While the present study combined the subsets for auditory and visual memory based on how the WMS-IV forms the indices, future studies may benefit from separating the immediate and delayed tasks into distinct constructs. This identifies whether the cognitive factors that underlie age-related change in immediate memory are different from those that subserve age-related decline in delayed memory.

In addition, the use of the Hayes' PROCESS Macros was not intended to facilitate the creation of first and second order factors or the examination of latent variables. While the present analyses may be informative regarding the different processes that underlie age-related memory change, other statistical procedures, such as structural equation modeling (SEM), may have been warranted. However, for the purposes of this study, Hayes' PROCESS Macros adequately tested the comprehensive cognitive model and provided informative results, on which researchers can build.

Finally, the present study represents a cross sectional examination of cognitive aging among adults, in which evidence of the complex cognitive changes that occur as individuals age was found in the between subjects examination. However, as is a limitation with any transectional examination of temporal-related change, the present study does not allow for an examination of within subject cognitive change as an individual ages. This is the benefit of longitudinal designs. However, considering the 52-year age span that the present study was able to capture by using a cross sectional design and data collected from 95 participants between the ages of 16 and 70 years, a longitudinal study would not have been feasible to achieve the same scope. Therefore, by incorporating an adequate distribution of ages within the sample and strict exclusion criteria to limit outliers, the present study's findings regarding the changes at the interindivdual level can be applied to understanding intrandividual cognitive aging.

Future Research

Age-related cognitive changes are an important area of research, particularly because of the potential obstacles they could pose to daily functioning given the increasingly aging population. The present study contributes a more refined understanding of the salient mechanism for cognitive decline due to normal aging and introduces a new focus for cognitive remediation strategies that aim to maintain cognitive fitness in older adulthood. The present study also highlights a number of areas for continued research. As researchers and clinicians investigate the factors that not only explain age-related memory decline, but possibly serve as the keys to preserving cognitive functioning into late life, future research must include samples that are more diverse. This will allow for better understanding of what ethnic, cultural, and linguistic differences exist with respect to cognitive aging. Future research should also involve samples that span adulthood (i.e., 16 to 100 years). Moreover, future research on cognitive aging will advance the field by clarifying: (1) the best fitting mediation model; (2) the effect of composites and their latent variables; (3) memory as a multi-sensory and multi-system domain; (4) the moderating role of education; (5) the cognitive mechanisms through which neuro-protective interventions combat age related cognitive decline; and (6) the effect of non-cognitive mediators.

The Hayes PROCESS Macros multiple mediator bootstrap methodology employed in the present study was not intended to capture goodness of fit for the model being tested. Rather, the Hayes' PROCESS Macros is often reserved for testing theoretically supported mediators. However, as the field continues to expand on what complex processes underlie age related cognitive decline, future research must incorporate in their model parameters for fit. Model fit is one of the advantages of structural equation modeling (SEM). Furthermore, more current versions of AMOS, the statistics software program that supports SEM analyses, allow for nonparametric bootstrapping. As the size of multiple mediator models grow, the challenge will be designing a model that best represents the underlying process rather than including irrelevant or collinear mediators.

In addition, the mediating variables under study were composites of second order variables. While the variables were found to have adequate psychometric properties as measures for the constructs, a more hierarchical analysis of the individual subtests as components of the larger composite/factor will likely aid in understanding the separate contribution of the subtests to the model. This is an area of study in which future investigations can build by constructing and testing models of fit.

With respect to the outcome variable memory, this domain is very complex in that it is a multi-sensory (i.e., auditory vs. visual vs. tactile) and multi-storage (encoding, short-term, long-term retrieval, and recognition) system. Depending on what is being tested (e.g., immediate vs. delayed), there will likely be a different influence of age. Furthermore, the mediated effect of both cognitive and non-cognitive factors will likely be dependent on the system or sensory modality, as has been uncovered by the present analysis. As such, future research is necessary to understand more fully how memory ages, as well as to examine models of mediation for more discreet outcome measures (i.e., visual, auditory, encoding, retrieval, recognition) that represent the complexity of memory.

As noted, level of education plays a significant role in maintaining cognitive functioning in healthy aging (Fritsch et al., 2009). While it was beyond the scope of the present analysis, the relationship between education and cognitive status is well known. Furthermore, there is conflicting but available evidence that education moderates the trajectory of cognitive change in later life. Regarding the direction of such moderation, early studies have found that higher levels of education reduce the presence of cognitive decline compared to that seen in older adults with lower levels of education. Updated studies regarding the influence of education on age-related changes in cognitive ability, as well as its moderating role on age-related cognitive decline, as well as the underlying mechanisms are needed (Zahodne et al., 2011). Understanding the sensitivity of cognitive factors to the variability in educational attainment will likely provide additional considerations when making conclusions about an individual's performance on such neuropsychological test and refines the process of interpretation and diagnosis.

In the field of cognitive rehabilitation, remediation and neuro-protective intervention, there has been significant emphasis on identifying targets through which interventions and techniques serve to restore or compensate for degeneration associated with aging. Among the more well-known is the ACTIVE Study, which was a multi-site cognitive training initiative that examined healthy older adults and identified ways to make significant cognitive improvements with appropriate cognitive training and practice (Ball et al., 2002). Additionally, there are efforts to examine pharmacological and photobiomodulation administrations of methylene blue as a means of targeting brain mitochondrial respiration to enhance cognition and protect against neurodegneration (Auchter, Williams, Barksdale, Monfils, & Gonzalez-Lima, 2014; Gonzalez-Lima, Barksdale, & Rojas, 2014). The present analysis introduces new considerations in the measurement and study of rehabilitation or neuro-protection of memory functioning such as the modality-related differences in memory decline along the adult age spectrum. Furthermore, the present study indicates that it is important for future research to consider verbal IQ as a protective factor that may support better auditory and visual memory as individuals age. As researchers seek to understand the impact of cognitive training/rehabilitation techniques as well as pharmacological or photobiomodulation interventions on memory decline, it will be relevant to map out sensory modality-specific pathways through the underlying cognitive mechanisms.

Another area of future research that will allow clinicians and researches to refine understanding of and address age-related cognitive decline, particularly in memory, will be to capture a more holistic picture of the factors that are influenced directly by age. Very few studies have examined physiological, social/lifestyle (i.e., occupation, activity level, socioeconomic status, etc.) neurochemical, neuroanatomical, cognitive, and psychiatric factors together for their role in cognitive aging.

As individuals age, they often experience a number of age-related physiological changes. Such changes have been found to occur in most if not all of the organ systems. As individuals age they experience increases in blood pressure, reduced cardiac output and the development of atherosclerotic plaque in the arterial wall - weakening the containment of blood as it flows to and from the heart. There are pulmonary changes related to reduced efficiency in the gas exchange and decreased lung capacity. Progressive elevations in blood glucose and increased occurrence of osteoporosis are also characteristic of older age (Boss, & Seegmiller, 1981). Understandably, there is also an increase in medications, as well as a reduction in the level of activity as individuals age.

Such changes have even been documented in the fourth and fifth decade of life, and have been linked to functional changes including reduced locomotion and muscle mass. Health related factors associated with aging such as arthritis and chronic pain, also have a pivotal influence on attention, endurance and speed.

There are also sensory changes to account for, which significantly influence an individual's ability to process information. The common cause hypothesis of cognitive aging posits that sensory functioning is significantly correlated with intellectual ability and memory for auditory and visual stimuli (Lindenberger & Baltes, 1994), particularly in the aging individual for whom the physiological architecture of the aging brain is changing (Luszcz & Bryan, 1999). Based upon this theory, older adults are believed to have greater memory difficulties than younger individuals because older adults' sensory acuity is poorer compared to that of younger individuals.

Psychiatric changes in mood and affect, secondary to the influence of age on neurochemical functioning, can influence a person's effort, motivation and task persistence. Moreover, factors such as nutrition and daily levels of stress may change over time to promote positive physiology and cognitive aging. However, the role of these factors, taken in concert with cognitive and non-cognitive variables is unclear. In many ways, the interprofessional and consultative nature of the field of clinical neuropsychology makes it well suited to address this gap in the literature by engaging the different specialties in collaboration. Certainly, with older adult population growing, future investigation should endeavor to grow the study of memory aging in this direction.

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