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EXECUTIVE FUNCTION, PROCESSING SPEED AND WORKING MEMORY AS MEDIATORS OF AGE-RELATED DECLINE IN VERBAL MEMORY ENCODING AND RETRIEVAL PROCESSES

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EXECUTIVE FUNCTION, PROCESSING SPEED AND WORKING MEMORY AS MEDIATORS OF AGE-RELATED DECLINE IN VERBAL MEMORY ENCODING AND RETRIEVAL PROCESSES

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ABSTRACT

EXECUTIVE FUNCTION, PROCESSING SPEED AND WORKING MEMORY AS MEDIATORS OF AGE-RELATED DECLINE IN VERBAL MEMORY ENCODING AND RETRIEVAL PROCESSES

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Tara L. Victor

The decline of memory with age is a well-established phenomenon. The purpose of this dissertation is to elucidate the mechanisms through which age exerts its effects on memory performance. The relative contributions of executive function, processing speed and working memory in age-related decline of verbal declarative memory have rarely been examined together, nor have their relationships with one another been fully explored as they pertain to age-related memory decline. Thus, taking each potential mediating variable into consideration, the present research seeks to test the empirical accuracy of an integrative, neuropsychological model of the cognitive aging process with respect to the two most basic memory processes – memory encoding and retrieval. All variables were measured using standard neuropsychological tests with a sample of 304 normal healthy older adults ranging from 54 to 92 years in age. Structural equation modeling indicated that much of the variance in cognitive performance among the mediators appeared to be shared. This is discussed in the context of the common cause hypothesis of age-related cognitive decline and in the context of suggestions for future research.

For my mother, Dr. Susan Cook

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INTRODUCTION

The elderly are the fastest growing segment of the U.S. population, yet the effects of aging on this groups' cognitive function are not well-known or sufficiently understood. This is coupled with the fact that this age group is vulnerable to increasing disabilities, many of which are the result of the aging central nervous system (CNS; Woodruff-Pak, 1997). Thus, as the number of older adults continues to increase, so does the importance of understanding the cognitive aging process. Our ability to identify the mechanisms that underlie cognitive decline in elderly populations has vast implications for the overall physical and psychological health of these individuals.

It is well documented in the literature that certain aspects of memory performance decline with age (see Ballota, Dolan & Duchek, 2000; Zacks, Hasher & Li, 2000, for recent reviews), and there have been many attempts to try and explain this phenomenon. One way researchers have tried to understand the decline of memory with age is by identifying the variables that mediate the relationship between these variables (see Luszcz & Bryan, 1999 for a review). For example, processing speed, or the speed at which an individuals processes stimuli perceived, (e.g. Bryan & Luszcz, 1996) has been shown to make a significant contribution to the age-related decline in memory performance. It is generally thought that with advancing age, people process information more slowly, and as a result, memory traces from previous experience may decay before later information is received, making linkages between information weaker. This is thought to lead to weaker and less elaborate encoding as well as difficulties during retrieval (Salthouse, 1991). In addition, working memory, the ability to simultaneously store and manipulate information, has been found to be a significant mediator in the age-memory relationship

(Baddeley, 1986, 1990; Lezak, 1995; Salthouse & Babcock, 1991). More specifically, decreased working memory is thought to have negative implications for one's ability to encode and retrieve information in memory due to limitations in one's ability to rehearse the to-be-remembered information, for example (Salthouse & Babcock, 1991). Finally, higher order cognition, known as executive function, has also been found to be a significant mediator of the relationship between age and memory performance (e.g. Troyer, Graves & Cullum, 1994) albeit to a lesser extent. Executive function is defined as the class of cognitive abilities thought to encompass the wide range of mental processes involved in problem solving. Examples of such processes include those involved in planning, strategic and abstract thinking, self-monitoring, shifting tasks and behavioral inhibition. More generally, executive abilities are those functions that control and integrate other cognitive actions, including memory (Lezak, 1995; Shimmamura, 1995). It has been suggested that age-related decline in executive function might limit the conscious and strategic aspects of memory performance, and this is thought to occur for both encoding (e.g., use of mnemonics) and retrieval (e.g., use of strategic search processes) (Moscovitch & Winocur, 1992). In this review, a focus will be placed on the mediating role of this particular theoretical construct in the relationship between age and memory as its role is the least well substantiated or understood. This is likely due, in part, to the fact that executive function is a very broad term used to describe a set of cognitive operations around which there exists much controversy concerning 1) its anatomical localization and 2) its usefulness as a unitary construct. These issues will be addressed in more detail later in this review.

Mediation is understood here in the Baron and Kenny (1986) sense as when the relationship between variables A and B is at least partially explained through variable C. In other words, variable C is said to mediate the relationship between variables A and B when it can be demonstrated as the mechanism through which variable A exerts at least part of its effects on variable B.

The overall purpose of this study then is to elucidate the mechanisms through which age exerts its effects on memory performance in a multivariate sense. Though the contributions of processing speed, working memory and executive function have been examined separately in different studies, the relative contributions of these mediating variables (processing speed, working memory and executive function) in age-related memory decline have rarely been examined together in a more comprehensive fashion, nor have their relationships with one another been fully explored as they pertain to age-related memory decline. In other words, the value of this study is that it examines these important relationships simultaneously. Thus, taking each potential mediating variable into consideration, the proposed research seeks to test the empirical accuracy of an integrative, neuropsychological model of the cognitive aging process with respect to the two most basic memory processes – memory encoding and retrieval. In particular, the models attempt to test the influences of working memory, processing speed and executive functioning on two aspects of verbal memory function, encoding and retrieval. Schematic representations of the proposed models for both processes are displayed in Figures 1 and 2, respectively. In order to assess the literature relevant to the development of these models, it will be necessary to: 1) briefly review the phenomena of age-related memory decline; 2) provide a review of the research surrounding the roles of these three focal constructs (processing speed, working memory and executive function) in the relationship between age and memory; and finally 3) identify the ways in which these mediating variables have been found to relate to each other in studies of age-related memory decline. Supported by the theory and research reviewed in the sections outlined above, the specific hypotheses pertaining to how these theoretical constructs might fit together in a comprehensive model of age-related memory decline will be offered along the way. They are listed separately only for clarity in defining the overall model, which is what of interest to this author. All study hypotheses are also listed in Table 1.

It is noteworthy to provide one caveat and that is the fact that these proposed models contain a number of individual mediational models, each of which could be tested in principle. Of interest in this study is the …..Can you include a paragraph describing the selection criteria and making explicit that these many other mediation models should, in principle, be tested also, but won't in this dissertation.

Age-Related Memory Decline

Types of Memory

Some aspects of memory have consistently been found to decline with age whereas others have not. Craik and Grady (2002) provide a taxonomy of memory that clarifies which types of memory are more vulnerable to the effects of aging. Whereas procedural, implicit, episodic recognition and semantic memory tasks seem to be relatively resistant to age, other tasks tapping episodic free-recall, contextual, source, working and prospective memory systems show large age effects. Shimamura (1990) also provides a taxonomy of memory including the implicit, prospective, and declarative memory systems. Within this classification system, implicit memory is defined as those memory functions that can be expressed unconsciously as in the acquisition of skills, classical conditioning and in priming where the individual will recall, as indicated by their performance, that they were involved in a previous experience even though they cannot recall the particular experience consciously. Prospective memory abilities are defined as those "processes and strategies by which one remembers to perform future actions" (p. 48). Relevant to the work of the present research, however, is the decline of functioning in the declarative memory system. Thus, the review of relevant findings will be limited to age differences in declarative memory functioning.

The declarative memory system is described by Shimamura (1990) as "the memory that is studied most often in psychological experiments, and it can be demonstrated on standard tests of memory (e.g. recall, recognition)" (p. 40). Unlike the implicit memory system, the declarative memory system involves "conscious or explicit memory of facts and episodes" (p. 40). This system is further described by Shimamura (1990) as important in "the establishment of memory representations during cognitive activities, such as elaboration, organization, rehearsal, and mediation" (p. 40). In other words, there are aspects of the declarative memory system that may likely be controlled or governed by those processes thought to characterize the mediating constructs of interest in this study, namely processing speed, working memory and executive functioning.

The declarative system is further thought to include both verbal and nonverbal types of memory (Shimamura, 1990). Verbal declarative memory, in particular, has been found to decrease as a function of age (Cellucci, Evans, Cattaruzza & Carter, 2001; Golski, Zonderman, Malamut, & Resnick, 1998; Paolo, Troester, & Ryan, 1997a, 1997b).

Specifically, in a cross-sectional study of older individuals ages 60 to 69 and 70 to 85, age-related deficits in this type of memory were found to be significant (Golski et al., 1998). Similarly, a study by Paolo and colleagues (1997a) found a decline in performance with age on a measure of verbal learning and memory, the California Verbal Learning Test (CVLT).

Memory Tasks

In terms of specific types of declarative memory tasks, age-related deficits have been found for free recall as well as recognition types of memory performance. In fact, age-related declarative memory deficits are particularly robust for free-recall memory performance (Burke & Light, 1981; Moscovitch & Winocur, 1995). Findings of decreased recognition memory performance with age, however, are described as only "reliable", and the relative strength of these associations is much smaller than for free recall (Moscovitch & Winocur, 1995; Parkin & Walter, 1991; Rabinowitz, 1984).

It has been suggested that recognition memory is perhaps more resistant to the effects of aging because it requires fewer cognitive resources, such as the mediators examined in this study (processing speed, working memory and executive function), to be carried out. The results of the study by Parkin and Walter (1992) indicated that an increase in non-contexually-based responses in a recognition memory task were related to poorer performance on the Wisconsin Card Sorting Test (WCST), a measure of executive function. This suggests that contextually-based recognition memory performance decreases as executive function declines in older adults, and that since free recall performance is thought to rely heavily on memory for context (Parkin & Walter, 1991), scores on this type of task would be even more strongly related to declines in executive function. This is consistent with the findings of other studies that have found executive measures account for little of the variance in recognition memory (Crawford, Bryan, Luszcz, Obonsawin & Stewart, 2000) but correlate highly with measures of free-recall memory (Ferrer-Caja, Crawford & Bryan, 2002). In addition, a study by Parkin & Lawrence (1994) found a correlation between differences in performance of recall and recognition and performance on the WCST in older adults. This makes intuitive sense because although free recall is thought to primarily involve the declarative memory system, as mentioned above, successful completion of this type of memory task also involves the ability to organize, manipulate, and retrieve information (Shimamura, 1990). To the extent that a memory task requires the implementation of strategies for successful remembering, executive functioning should be an essential cognitive mediator. This is consistent with Moscovitch and Winocur's (1995) "working with memory" theory, which suggests that while the prefrontal cortex functions to implement encoding and retrieval strategies, and would therefore be more important for the successful completion of free-recall memory tasks, the hippocampus is the source of pure memory, and therefore, what is taped during tasks of recognition memory.

Furthermore, to the extent that a memory task requires adequate processing speed and the effective functioning of working memory abilities, then these processing resources should also be essential cognitive mediators. Park and colleagues (1996) found that working memory mediated part of the relationship between processing speed and memory performance for free and cued recall tasks (recall in the context of no additional information and recall after being provided with a cue for remembering, respectively), but not for spatial memory tasks (recall of the spatial layout or sequencing of visually presented information); in other words working memory was implicated in those types of memory tasks thought to require the use of more resources. Thus, the extant literature clearly indicates that free recall is a memory task more likely to depend on the effective functioning of processing resources such as executive function, processing speed and working memory than other types of memory tasks such as recognition memory tasks, for example, which involve the use of cues to aid recall and place less demands on cognition. One would expect this to be the case in the present sample.

> Hypothesis 1: Free-recall memory will rely on the mediating resources (processing speed, working memory and executive function) to a greater extent than will recognition memory. That is, links u, w and x in Figure 3 will be expected to be stronger than links cc, ee and ff in Figure 4.

However, less is known about the importance of these mediators with respect to their impact on memory processes, such as encoding and retrieval.

Memory Processes

It was Craik (1986) who suggested that it might be helpful to refine our understanding of the memory difficulties we see in older adults by thinking in terms of the *processes* involved in memory performance (i.e., encoding and retrieval). Along these lines, both behavioral and neuroimaging research over the years have indicated that older adults have deficits in both encoding and retrieval (see Craik & Grady, 2002 for a review). In addition, theorists have speculated that these memory processes likely depend on the three processing resources of interest in this study, maybe to a greater or lesser extent depending upon the memory process examined. For example, Craik, Govoni, Navah-Benjamin and Anderson (1996) found that when they divided subjects' attention (one aspect of executive function) at encoding, their performance suffered significantly.

However, when their attention was divided at retrieval, their performance was less affected. This suggests that executive function may be a more important mediator at encoding versus retrieval. Little research has examined the relationship between executive function and specific memory processes (the only study found by this author was by Bryan, Luszcz and Pointer in 1999, which found executive function and working memory, but not processing speed, to be important mediators of memory encoding). Further, little research has examined the relative contributions of all three potential mediating variables on the different memory processes of encoding and retrieval. Thus, the present study seeks to explore the relative contributions of processing speed, working memory and executive function in the relationship between age and memory encoding on the one hand and the relationship between age and memory retrieval on the other.

In sum, it is clear that an examination of the literature reveals the finding that verbal declarative memory declines during the aging process. Unclear, however, are the mechanisms through which the aging process exerts its effects on these memory functions. Researchers have developed different hypotheses as to the nature of the variables potentially mediating the age-memory relationship and, stated in a statistical sense, the extent to which they eliminate or attenuate the age-related variance in memory performance.

Potential Mediating Variables

Craik and Byrd (1982) have suggested that the decline of memory with age is a function of older adults becoming limited in their capacities for processing information. Operating under this assumption, many researchers have sought to identify the specific areas of processing potentially mediating this decline. The majority of this research has operationalized this cognitive processing variable through measures of processing speed and working memory, and the importance of these constructs in age-related memory decline is well established (see below). More recently, however, the potential mediating role of central executive functioning has also been entertained. The research surrounding the potential mediating roles of each of these three areas of cognition in the age-memory relationship is discussed below with particular attention placed on the more recent research concerning the role of executive functioning.

Processing Speed

One area of functioning that has been given considerable attention in the literature with respect to age-related cognitive decline is that of processing speed, or the number of cognitive operations that can be carried out at any one time (Gronwall, 1989). Specifically, Salthouse (1980, 1985, 1996a) has argued that memory performance may be negatively affected as one ages because of a decline in the speed at which the central nervous system (CNS) processes information.

Indeed, there have been consistent reports of a decrease in processing speed with age (Fisk & Warr, 1996; Salthouse, 1985; Spreen & Strauss, 1998). In addition, processing speed has been found to account for a significant amount of the age-related variance in cognitive ability, generally (Park et al., 1996), and in the relationship between age and more specific types of cognitive abilities such as reasoning and integration (Salthouse, 1993), working memory (Salthouse & Babcock, 1991; Park et al., 1996), fluency and knowledge (Lindenberger, Mayr, & Kliegl, 1993), and decision accuracy and decision time (Salthouse, 1994). In addition, processing speed has been found to mediate the relationship between age and paired-associated (requiring recall after receiving a cue) and free-recall (requiring active, conscious search processes) measures of memory (Bryan & Luszcz, 1996; Lindenberger et al., 1993; Nettelbeck & Rabbitt, 1992; Salthouse, 1993), as well as other aspects of memory performance (Hultsch, Hertzog, & Dixon, 1990; Luszcz, 1992; Salthouse, Kausler, & Saults, 1988; see Salthouse, 1991 for a review).

Evidence supports the idea that processing speed is a relevant mechanism through which age exerts its effects on memory performance. More recent research (Salthouse, 1996a) has also provided more information about the role of processing speed in the decline of memory with age. Specifically, it seems that the speed factor may have a more general influence as opposed to linkages with specific types of memory functions. It is generally thought that with advancing age, people process information more slowly, and as a result, memory traces from previous experience may decay before later information is received, making linkages between information weaker. This places constraints on the amount of elaboration and rehearsal possible, leading to weaker encoding as well as difficulties during retrieval (Salthouse, 1991, 1996). Evidence for this hypothesis includes studies that have found age differences in memory performance *increase* when encoding strategies are used (Kliegl, Smith & Baltes, 1989; Light 1991; Verhaeghen, Marcoen & Goossens, 1992) as well as a study that found age-related slowing to be correlated with choice of encoding strategy; older adults were less likely to choose elaborate encoding strategies as compared to younger adults. It seems that younger adults are either better able to implement, or benefit from the use of, effective encoding strategies in a way that older adults cannot, and this is thought to be because of diminished processing resources in the older adult population. Thus, the specific mediational process is hypothesized to occur in the following way: Getting older leads to a physiological slowing of the central nervous system. This general slowing of information processing makes it more difficult to encode information into memory by making linkages between information weaker, subsequently hindering elaboration and rehearsal. This slowing also likely negatively impacts retrieval of information from memory through it's impact on encoding or because information is retrieved too slowly to be useful.

Hypothesis 2a: Processing speed will mediate the relationship between age and verbal memory encoding (links a and e in Figure 1).

Hypothesis 2b: Processing speed will mediate the relationship between age and verbal memory retrieval (links i and m in Figure 2).

However, processing speed does not account for all the age-related variance found in memory performance. This suggests that there are other theoretical constructs involved in this relationship. Park et al. (1996) found perceptual speed to mediate the age-memory relationship, but this mediation occurred, in part, through working memory. Indeed, working memory has also been investigated in terms of its potential mediating role in the relationship between age and memory.

Working Memory

Working memory is defined as the ability to simultaneously store and manipulate information (Baddeley, 1986, 1990; Lezak, 1995). Older adults have been found to perform significantly worse on measures of working memory as compared to younger adults (Baddeley, 1986, 1990; Charness, 1987; Fisk & Warr, 1996; Light & Anderson, 1985; Salthouse, 1988; Salthouse & Babcock, 1991; Balota et al., 2000 and Zacks et al., 2000 provide recent reviews). In addition, working memory has also been found to mediate the relationships between age and a number of different cognitive abilities, including the relationship between age and memory (Campbell & Charness, 1990; Foos, 1989; Salthouse, 1992a; 1993; Salthouse & Babcock, 1991; Van der Linden, Bredart, & Beerten, 1994). Thus, some researchers have postulated a two-factor resource model that includes both perceptual speed and working memory (Park et al., 1996; Mayr & Kliegl, 1993; Nettelbeck & Rabbitt, 1992; Bryan & Luszcz, 1996).

However, there is some discrepancy in the literature as to whether working memory and processing speed mediate the relationship together or if working memory actually serves as a secondary mediator between processing speed and memory performance. For instance, Mayr and Kliegl (1993) and Nettelbeck and Rabbitt (1992) found these two theoretical constructs work as independent mediators to account for the age-related variance in memory performance. However, Park et al. (1996) found speed to be the sole mediator, accounting for all of the age-related variance in memory performance with working memory serving as a secondary mediator through which speed, in part, exerted its effect on memory. This latter finding was also supported in a study by Salthouse and Babcock (1991) where age-related deficits in working memory were investigated. Their findings suggested that the relationship between age and working memory was mediated by perceptual speed, as results showed that the age-related variance in working memory performance was significantly reduced when perceptual speed was statistically controlled. Similar findings came out of other research by Salthouse (1992a) in which the results of two studies indicated that processing speed accounted for a significant portion of the age-related variance in working memory performance in a sample of participants ranging from 18 to 80 years of age. Thus, it appears that the majority of evidence indicates that both perceptual speed and working memory play very important roles in the decline of memory with age and that both should be considered in any theoretical account of this phenomenon. It also appears that the influence of working memory may be one of secondary importance, mediating the relationship between processing speed and memory. Explained on a theoretical level, age leads to a general slowing of CNS processing that, in turn, limits the amount of information one can juggle in mind at any given fixed unit of time. This would likely be at both encoding when one is trying to keep information in working memory to transfer to long-term storage and retrieval when one is trying to access and hold in working memory information she/he is interested in using in some way:

> Hypothesis 3: Processing speed will mediate the relationship between age and working memory (links a and d in Figure 1 and links i and l in Figure 2).
>
> Hypothesis 4a: Working memory will mediate the relationship between processing speed and verbal memory encoding (links d and g in Figure 1).
>
> Hypothesis 4b: Working memory will mediate the relationship between processing speed and verbal memory retrieval (links l and o in Figure 2).

It should be noted that even though working memory is often considered to be a component of executive functioning (this is discussed in detail below), it has also already been consistently shown in previous research to mediate the age-memory relationship as described above. What is less clear, however, is the extent to which other aspects of executive functioning mediate the relationship between age and memory, and how these other aspects of executive function relate to the more well-established mediators of age-related memory decline (i.e., processing speed and working memory). As Hultsch, Hertzog, Dixon and Small (1998) point out, there are cases in which age remains a significant mediator of memory performance even after processing speed and working memory have been accounted for. In fact, their research on the Victoria Longitudinal Study of memory and aging suggests that age differences in memory are mediated by variables other than processing speed and working memory. Indeed, the theoretical construct of executive function has more recently been considered in terms of its potential to influence the age-memory relationship; however, its role is less well understood. Thus, the majority of what remains in this review focuses on the potential mediating role of executive function.

Executive Function

Executive function includes a wide range of cognitive abilities involved in problem solving such as planning, strategic and abstract thinking, self-monitoring, shifting tasks and behavioral inhibition (Lezak, 1995; Shimamura, 1995). These functions thought to characterize the central executive include those aspects of cognitive activity that control and integrate other cognitive actions, including memory (Lezak, 1995; Shimamura, 1995). These conscious functions work to develop strategies for success and orient towards goal-directed behavior (Lezak, 1995). Researchers have proposed that age-related declines in these functions create the disruption in memory function experienced by many individuals in the normal elderly population (Dempster, 1992; Ferrer-Caja et al., 2002; Moscovitch & Winocur, 1992; Parkin, 1996; Troyer, Graves & Cullum, 1994; Woodruff-Pak, 1997). More generally known as the frontal lobe hypothesis of cognitive aging (Albert & Kaplan, 1980; Dempster, 1992; West, 1996), it has been proposed that age-related declines in these frontal lobe, or executive, functions create a disruption in many areas of cognitive ability, generally, and in memory function in particular (Dempster, 1992; Fuster, 1989; Moscovitch & Winocur, 1992; Parkin, 1996;

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West, 1996). In fact, several theories of frontal lobe functioning exist, including the following: 1) Fuster's (1989) hierarchical model of the prefrontal cortex; 2) West's (1996) theory that the prefrontal cortex performs integrative functions, supported by four secondary processes (retrospective memory, prospective memory, interference control, and inhibition of prepotent responses), which in turn, support a wide array of other cognitive functions; and finally, 3) Moscovitch and Winocur's (1995) suggestion that the prefrontal cortex subserves a "working with memory" function. More specifically, these authors suggest that while the hippocampus is the source of pure memory, the prefrontal cortex "works with" memory to order memories in time and context, as well as to implement encoding and retrieval strategies.

Recall that the declarative memory system was described by Shimamura (1990) as being important in "the establishment of memory representations during cognitive activities, such as elaboration, organization, rehearsal, and mediation" (p. 40). In other words, there are aspects of the declarative memory system that may be controlled or governed by those processes thought to characterize the construct of executive functioning. Specific hypotheses concerning the relationship between frontal function and memory performance have revolved around the idea that inadequate frontal function interferes with those processes necessary for successful encoding and retrieval of information. In terms of acquisition, theorists have postulated that older adults do not utilize mnemonic strategies effectively to organize and elaborate information at encoding which impairs their memory performance relative to younger adult groups (Craik & Lockhart, 1972; dellaRocchetta, 1986; Poon, 1985). Thus, executive function may work to initiate and implement the use of mnemonic strategies in this way (Moscovitch &

Winocur, 1992). In terms of retrieval, it has been suggested that older adults have difficulty using strategic and conscious processes for successfully accessing information to be recalled (Moscovitch, 1989; Moscovitch & Winocur, 1992). An alternative explanation lies in the difficulty older adults may have in overcoming the effects of interference in their cognitive processes, and that this may have negative implications for both encoding and retrieval memory processes (Hasher & Zacks, 1988; Stuss et al., 1982).

There is considerable evidence to support the hypothesis that executive function mediates the relationship between age and memory, and this evidence can be found in both the behavioral and neuroimaging literatures. Some of this research, however, must be interpreted under the assumption that executive functioning processes are anatomically localized in the frontal lobes of the brain, and indeed, there is considerable evidence to support this assumption (Lezak, 1995; Moscovitch & Winocur, 1992; Stuss & Benson, 1986). Thus, before examining the evidence suggesting that executive functioning serves as a mediator in the relationship between age and memory, it is first necessary to discuss this construct's association to the frontal lobes of the brain.

Executive function and the frontal lobes of the brain.

The relationship between executive function and the frontal lobes of the brain has been supported in a number of studies demonstrating that executive function measures are sensitive to frontal lobe damage. Specifically, the Wisconsin Card Sorting Test (WCST; Heaton, 1981), a standard measure of executive functioning thought to assess hypothesis formation and set-shifting (Moscovitch & Winocur, 1995), has been shown to be sensitive to dysfunction in the frontal lobes' neurological connections with other areas of the brain (Arnett et al., 1994) and has been associated with the activation of the frontal lobes using PET technology (Berman et al., 1995). In addition, the WCST has been described as a measure of concept formation processes and inhibition of inappropriate responses, operations thought to be controlled by the frontal lobes of the brain (Arnett et al., 1994). Poor performance on another standard test of executive function, the Stroop Color Word Test (Stroop; Golden, 1978), thought to measure the ability to ignore competing but irrelevant information, has also been associated with focal frontal lobe damage (Van der Linden, Bruyer, Roland, & Schils, 1993; Perret, 1974; Holst & Vilkki, 1988). The Trailmaking Test (TMT; Reitan, 1958) is another test of executive function that has been described as a measure of frontal lobe functioning (Reitan, 1958; Picton, Stuss, & Marshall, 1986). Finally, performance on tests of verbal fluency has also been associated with frontal lobe function. Studies reported by Moscovitch and Winocur (1995) include those in which deficits in the letter fluency task have been found in individuals with left orbitofrontal lesions. In another study, verbal fluency was also found to decline when prefrontal pathology was present (Crowe, 1992). A recent review examining the localization of frontal lobe processes concluded that WCST, Stroop and Trailmaking Test performance was largely reflective of left dorsolateral and superior medial frontal functioning, with additional reliance on the right dorsolateral frontal lobe for the WCST and Trail Making performance, but not for performance on the Stroop Test (Stuss et al., 2002).

Thus, there is considerable evidence linking executive functioning to the integrity of the frontal lobes of the brain. It is noteworthy to mention, however, that dysfunction in executive processes can also occur after injury to other brain areas (Lezak, 1995). More recently, researchers have questioned whether the functions forming what is collectively referred to as the construct of executive function are actually localized in the frontal lobes (Parkin, 1998). Some have even called into question the usefulness and empirical accuracy of the executive functioning concept itself (e.g. Parkin, 1998). They argue that executive functioning processes are not specifically linked to frontal regions of the brain and, in fact, the use of the term 'executive functioning' as a general, all-encompassing construct for many underlying cognitive abilities is misled and empirically unjustified. These researchers argue that the literature actually points to the localization of executive functions in many different areas of the brain depending on the specific ability in question. These arguments certainly have some merit. However, the relationship between executive function and the frontal lobes of the brain is supported by much empirical research.

Working within this theoretical framework of localization of function in the frontal lobes of the brain, three lines of evidence implicating a potential mediating role of executive functioning in the relationship between age and memory have be identified by Bryan and Luszcz (1999). First, there is an accumulation of evidence suggesting that executive functioning, as measured by a number of standard neuropsychological tests assessing this aspect of cognition, decreases with age. The second line of research includes evidence suggesting that there is actual neurodegeneration of the frontal lobes of the brain during the aging process. The third line of research concerns the striking similarities found between memory deficits associated with aging and those deficits that result from frontal lobe injury. A fourth line of evidence identified by this author is the vast number of neuroimaging studies implicating frontal lobe activation during memory tasks. These four lines of research are discussed below.

(1) Age-related decline in executive function.

The first of the four lines of research in support of the executive functioning hypothesis is evidence suggesting that performance on standard measures of executive functioning declines with age. Based on their research findings, Albert and Kaplan (1980) developed what is known as the Frontal System Hypothesis, formed from their conclusion that older adults "do not develop adequate techniques for selectively attending to material" (p.416). Their research found that when confronted with a task requiring the use of systematic and organized strategies for success, elderly individuals tend to display inadequacies in performance; in other words, inadequacies in executive functioning.

There are many other studies indicating that older adults perform significantly worse than younger adults on tests of executive functioning (Haaland, Vranes, Goodwin, & Gary, 1987; Mittenberg, Seidenberg, O'Leary, & DiGuilio, 1989; Nielson et al., 2002; Whelihan & Lesher, 1985). Mittenberg et al. (1989) analyzed the performance of elderly individuals on a series of neuropsychological tests and determined, using factor analytic techniques, that functions associated with the frontal lobes of the brain were the primary components of observed cognitive impairment. Similarly, on one measure of frontal lobe functioning, the Self-Ordered Pointing Task (SOPT), older adults have consistently been found to perform worse as they enter the sixth decade of their lives (Diagneault & Braun, 1993; Shimamura & Jurica, 1994, Toros, 2001). In addition, poorer performance on the Stroop Test with advanced age have been consistently demonstrated (Boone, Miller, Lesser, Hill, & Elia, 1990; Houx, Jolles, & Vreeling, 1993; Spreen & Strauss, 1998; Uttl & Graff, 1997) with age effects most prominent on the color-word interference trial

(Cohn, Dustman, & Bradford, 1984; Diagneault, Braun, & Whitaker, 1992; Macleod, 1991). Whelihan and Lesher (1985) found the older group of subjects in their study to have lower scores on six different tests of executive functioning including the Stroop Test. Age differences on the Trail Making Test (Kennedy, 1981) have also been found. Further, there is also evidence to suggest a decline in performance with age on the Wisconsin Card Sorting Test (WCST) (Leach, Warner, Hotz-Sud, Kaplan, & Freedman, 1991) that is most notable for the increase in perseverative errors in older groups (Craik et al., 1990; Toros, 2001) and it is these types of errors that are the most strongly associated with frontal dysfunction (Heaton, 1981). Boone, Ghaffarian, Lesser, Hill-Gutierrez, and Berman (1993) conducted a study instituting a cross-sectional design to determine age-related differences on the WCST and found that older subjects performed worse on two different measures of this test of executive functioning as compared to younger adults. Other studies have found similar age-related performance deficits on the WCST (Mejia, Pineda, Alvarez & Ardila, 1998). Finally, executive functioning proved to be an age-related phenomenon in a study conducted by Parkin and Walter (1992) as older adults were found to perform significantly worse than younger adults on all measures executive functioning used including the WCST.

It is important to note, however, that there has been some inconsistency in the literature with respect to age-related decline in executive function. For example, Haaland et al. (1987) found a decline in the number of completed categories and an increase in total errors on the WCST for those individuals older than 80 years of age; however, these researchers did not find an increase in perseverative errors or significant failures to maintain set in this older group of individuals. In addition, no impairments on this test were found for those older adults between the ages of 64 to 80. Similarly, Benton, Eslinger, & Damasio (1981) found that adults over 80 years were impaired on a test of verbal fluency, but did not find such impairment in the younger comparison group used. Thus, there are some studies that do not indicate a decline in executive functioning with age, but the majority do indicate such age-related impairment.

(2) Age-related frontal lobe degeneration.

The second line of research linking this neuropsychological construct to age-related memory decline includes evidence suggesting that the frontal lobes of the brain are affected by age (Albert & Kaplan, 1980; Shimamura, 1990; West, 1996; Woodruff-Pak, 1997; see Raz, 2000, for a review). There are indeed a number of neuropathological and in vivo neuroimaging studies that suggest the prefrontal cortex is a brain region strongly affected by the aging process (Coleman & Flood, 1987; Mamo, Meric, Luft, & Seylaz, 1983; Raz, Torres, Spencer, & Acker, 1993; Tachibana, Meyer, Okayasu, & Kandula, 1984). For example, some studies link the normal aging process to structural abnormalities in this area of the brain (Squire, 1987; Haug et al., 1983). Specifically, Squire (1987) conducted a review of the studies of neuronal loss during the aging process and one of his conclusions was that the "losses from the prefrontal cortex may be sizeable, even in terms of a daily estimate" (p.119). Similarly, Haug and his colleagues (1983) identified significant neuronal loss in the prefrontal cortex with age. Many researchers have actually suggested that deficits of frontal lobe function are the first deficits found to arise in the normal aging process (Albert & Kaplan, 1980; Diagneault, Braun, & Whitaker, 1992; Fabiani, Friedman & Cheng, 1998; Ragland et al., 1997; West, 2000). Similarly, in his recent review, Raz (2000) concluded that age-related changes in brain volume appear to be greatest in the prefrontal cortex and neostriatum. However, it should be noted that a recent review by Greenwood (2000) concluded that researchers are not paying enough attention to evidence that suggests other areas of the brain change with age as well.

Combined with the research cited above is a third line of evidence in support of the executive functioning hypothesis. This research concerns the similarity found between memory deficits associated with aging and those deficits that result from frontal lobe injury. Again, the rationale behind this supporting evidence relies on the relationship between executive function and the frontal lobes of the brain.

(3) Similarity between age-related memory deficits and those associated with frontal lobe injury.

The third line of research lending support to the idea that executive functioning may play a mediating role in the relationship between memory and age is the evidence suggesting there is a remarkable similarity between the memory deficits found in normal older adults and deficits in those individuals with frontal lobe lesions. Recent reviews of the literature in this area point to these similarities in deficits of free recall performance, sequencing of responses, and memory for spatio-temporal context (Luszcz & Bryan, 1999; Moscovitch & Winocur, 1995; Petrides & Milner, 1982; Squire, 1987). Indeed, many studies have reported correlations between standard neuropsychological tests of frontal dysfunction and measures of certain types of memory including temporal order (Milner, Petrides, & Smith, 1985), source (Craik et al., 1990; Shimamura, Janowsky, & Squire, 1991; Schacter, Harbluk, & McLachlan, 1984) and episodic (Parkin & Walter, 1991; Troyer, Graves, & Cullum, 1994) memory. Other studies also indicate potential dependence of memory functions such as the release from proactive interference (the ability to free up learning processes for continuing exposures to new information) (Lezak, 1995; Squire, 1982) and normal free recall relative to recognition (Hanley, Davies, Downes, & Mayes, 1994; Parkin, Yeomans, & Bindschaedler, 1994) on the integrity of frontal lobe function. Still, other studies linking frontal function with memory have found that a greater number of perseverative errors on the WCST is related to poorer fact recall and poorer contextual memory (Spencer & Raz, 1994). Stuss and colleagues (1996) compared both older and younger adults with three groups of patients with frontal lobe lesions (unilateral left, unilateral right and bilateral) on a measure of verbal learning, and found that the performance of the clinical groups was more similar to the older as compared to younger subjects in the sample. More specifically, the older group and the frontal lobe damage groups demonstrated similar difficulties with executive-type organizational tasks and memory retrieval.

Indeed, Moscovitch and Winocur (1995) argue that the more resource-dependent retrieval processes characterizing free recall memory performance are mediated by the frontal lobes and hippocampal system of the brain whereas the retrieval processes associated with recognition performance are mediated by the hippocampal system only. The former claim is supported by the findings of many different studies (Moscovitch, 1989; Moscovitch & Umilta, 1990; Moscovitch & Umilta, 1991; Wheeler, Stuss & Tulving, 1995). Wheeler and colleagues (1995) performed a meta-analysis of the effects of frontal lobe damage on episodic memory performance. Results indicated marked deficits in free recall performance. It was noted by Moscovitch and Winocur (1995) that individuals with frontal lobe damage seemed to show impairment when the memory task called for organizational or strategic abilities for successful completion, such as in a task involving the recall of stories or the recall of categorized lists of words; both of these tasks require the use of organization and strategy. In addition, they note that when the structure is provided by the experimenter, the memory deficits seen in these frontal lobe impaired individuals is very much reduced or even eliminated. In their more recent review of the literature concerning the role of frontal lobe functions in memory tasks, Moscovitch and Winocur (2002) write, "…the [frontal cortex] is required if accurate memory depends on organization, search, selection and verification in the retrieval of stored information. The important point that emerges is that the [frontal cortex] is less involved in memory recollection per se, than it is in mediating the strategic processes that support memory encoding, recovery, monitoring and verification" (p.188). These authors further elaborate on their model by saying that the hippocampus and other medial temporal lobe and diencephalic systems are "raw memory" structures, damage to which causes clear anterograde amnesia (recall the famous case of H.M.) while the frontal lobes work with these raw memory structures when environmental supports for cueing are nonexistent, as in the case of free-recall memory tasks.

(4) Neuroimaging studies of frontal lobe functions during memory tasks and memory processes.

Finally, the fourth line of evidence is the vast number of neuroimaging studies implicating frontal lobe activation during memory tasks. For instance, Johnson, Saykin, Flashman, McAllister and Sparling (2001) found that recognition discriminability scores on the California Verbal Learning Test (CVLT) were related to fMRI signal increases in the right prefrontal cortex for familiar words. With respect to memory processes, in younger adults, it has been shown that the prefrontal cortex is activated while they perform episodic encoding and retrieval functions (see Cabeza & Nyberg, 2000 for a review) and this activation is lateralized depending on the function performed; *encoding* generates left prefrontal activation (Lepage, Habib & Tulving, 1998) while *retrieval* generates right activation (Fletcher, Shallice, Frith, Frackowiak & Dolan, 1998; Nyberg, Cabeza & Tulving, 1996, 1998; Tulving, Kapur, Craik, Moscovitch & Houle, 1994).

However, the data are different for older adults. With respect to *encoding*, older adults as compared to younger adults have been found to show less activation of left prefrontal and temporal brain regions during encoding of unfamiliar faces (Grady et al., 1995, 2002) and verbal paired associates (Cabeza et al., 1997). Older subjects in these studies also performed worse when later recognizing this information. In addition, older adults have been shown to exhibit less left prefrontal activation while making semantic judgments about words as compared to their younger counterparts, suggesting that they may experience deficits in their ability to encode material (Stebbins et al., 2002). Together, these findings suggest that aging may reduce one's ability to encode information effectively, reducing declarative memory performance in the elderly, and that this decline in ability is linked, in part, to diminished left prefrontal function.

In studies investigating the neural correlates of *retrieval* processes, the right prefrontal cortex is more active than the left in younger adults whereas there is bilateral prefrontal activation in older adults (Cabeza et al., 1997; Grady, Bernstein, Beig & Siegenthaler, 2002). In addition, retrieval appears to be mediated equally by the frontal lobes and other posterior cortical regions, reflecting a lack of localization specificity for this particular memory function as compared to memory encoding (Cabeza et al., 1997;

Grady et al., 2002). I will return to the former finding of lack of *hemispheric asymmetry* in older adults later in this review; however, with respect to the latter finding that there also appears to be a lack of *localization* for retrieval memory processes, the studies upon which this conclusion is based only used tasks of recognition and cued recall, which are less resource-dependent tasks. As Craik and Grady (2002) point out, there are "no neuroimaging experiments to date [that] have examined free recall, the memory task on which older adults show the greatest deficit" (p. 531). In addition, as indicated earlier, free-recall is the most resource intensive measure of memory, and likely depends on the frontal lobes to a much greater extent. Thus, it may not be surprising that the frontal lobes were not differentially activated during retrieval tasks in the studies mentioned above, as they only used less-resource intensive measures of memory performance.

In sum, it is thought that aging leads to a degenerative process in the frontal lobes of the brain, manifested in executive function deficits that, in turn, lead to difficulties in memory encoding and retrieval. At encoding, decreased executive function might translate into the decreased use or nonuse of mnemonic and other organizational strategies helpful for acquiring new information into memory. At retrieval, decreased executive function might make it difficult to use strategic and conscious processes for successfully accessing information to be recalled, such as systemically retracing one's steps in order to find where one left her reading glasses, for example.

> Hypothesis 5a: Executive function will mediate the relationship between age and verbal memory encoding (links b and h in Figure 1).

> Hypothesis 5b: Executive function will mediate the relationship between age and verbal memory retrieval (links j and p in Figure 2).

In sum, the research suggests that processing speed, working memory and executive function are all potential mediators of the relationship between age and memory. The next question is: How are the mediators related to one another as they intervene in the relationship between age and memory. The next section reviews the literature relevant to this question, and then specific hypotheses are offered to complete the explanation of the models being evaluated in this investigation.

The Relationships Between the Mediators

Processing Speed and Working Memory

Recall the study by Park et al. (1996) which found speed to be the sole mediator, accounting for all of the age-related variance in memory performance with working memory serving as secondary mediator through which speed, in part, exerted its effect on memory. Also recall that this latter finding was supported in studies by Salthouse & Babcock (1991), Van der Linden et al. (1999), and Hultsch et al., (1998) whose findings suggested that the relationship between age and working memory was mediated by perceptual speed. In addition, other studies have found that processing speed eliminated all of the age-related variance in working memory performance (e.g. Fisk & Warr, 1996). Thus, as indicated previously it appears that the influence of working memory on verbal memory performance is one that occurs secondary to the influence of processing speed. This relationship is addressed in Hypotheses 3 and 4 above.

Processing Speed and Executive Function

Previous research has indicated that controlling for processing speed removed most of the age-related variance in executive function. However, controlling for executive function left 60% of the variance in processing speed attributable to age (Fisk

& Warr, 1996). Another study by Andres and Van der Linden (2000) also indicated that part of the age-related decline seen in older adults on measures of planning is related to reduction in speed of processing. In addition, research by Uttl and Graf (1997) suggested to these authors that performance on a version of the Stroop test (a widely used measure of executive function) could be attributed to the effects of age-related general slowing. These results are consistent with the findings of other studies that processing speed mediates age-related decline in performance on measures of executive function (e.g., Salthouse, Fristoe & Rhee, 1996). However, other research has indicated that while processing speed attenuates the relationship between age and executive function, age still accounts for a significant portion of the variance in executive function (Lowe & Rabbitt, 1997; Keys & White, 2000). In fact, even in the Andres and Van der Linden (2000) study mentioned above, processing speed was not able to account for all of the age-related decline seen in a second aspect of executive function, namely inhibition. These latter findings coupled with the fact that Fisk and Warr (1996) suggested their test of executive function may not have been sensitive enough indicates that while age may exert some of its effects on executive function through processing speed, it is likely that age also directly affects executive function as well, and it is specifically likely that it is inhibitory executive processes that are directly affected by age. Thus, executive function is hypothesized to be an independent mediator in the relationship between age and memory (Hypothesis 5), but executive function is also expected to mediate the relationship between processing speed and memory performance based on the aforementioned research. Theoretically, slowed processing speed likely inhibits the older adult's ability to efficiently plan and organize strategies needed for successfully memory encoding and retrieval. The impact of processing speed on executive function and, in turn, memory processes might also be explained by the impact of slowed processing speed on the older adult's ability to effectively filter out irrelevant stimuli (an executive ability); it would take longer to determine what it and is not of importance in a given situation. It would also take longer to overcome the effects of interference, another aspect of executive function. This, in turn, would lead to decreased memory performance, as the older adult becomes distracted by interfering and irrelevant stimuli.

> Hypothesis 6a: Executive function will mediate the relationship between processing speed and verbal memory encoding (links c and h in Figure 1).
>
> Hypothesis 6b: Executive function will mediate the relationship between processing speed and verbal memory retrieval (links k and p in Figure 2).

Working Memory and Executive Function

Working memory has long been thought of as an aspect of cognition underlying the rubric of executive function, and the neuroimaging literature is consistent with this idea, as working memory processes have been localized in the frontal lobes of the brain. More specifically, frontal control over working memory tasks has been localized to the dorsolateral prefrontal regions (Craik & Grady, 2002; Petrides, Alivisatos, Meyer & Evans, 1993). D'Esposito and Postle (2002) provide a more specific review of the localization of working memory abilities in the frontal lobes of the brain, indicating not only that the dorsolateral prefrontal cortex is important for working memory, but that it is particularly important for encoding processes. They also propose that the lateral prefrontal cortex is organized by content with the maintenance of verbal stimuli strongest in the left posteroinferior prefrontal cortex, and maintenance of spatial weakly lateralized to the right hemisphere. Thus, working memory has been thought of as an aspect of executive function and has been localized in frontal regions of the brain.

However, in the present research the constructs of executive functioning and working memory will be considered separately. There exists theoretical literature to support the separation of these constructs (Moscovitch & Winocur, 1992; Moscovitch & Umilta, 1990) and factor analyses have revealed loadings on separate factors for measures of working memory and executive functioning (Bryan, 1998). In addition, one of the more well-known cognitive models of working memory function is that of Baddeley (1986, 1990) which breaks down working memory into the phonological loop and the visuospatial sketchpad. Both have strong storage/rehearsal functions for verbal and visuo-spatial information, respectively, and both are controlled by a central executive, "an attentional control system, capable of integrating the two slave systems, of linking them with information from long-term memory, and of manipulating the resulting representation" (Baddeley, 2002, p. 246). Thus, in Baddeley's model the central executive construct is separate from, but related to, the working memory construct; in this view the central executive controls working memory processes.

Similarly, in the theoretical view of Hasher and Zacks (1988; Zacks & Hasher, 1994), working memory and inhibitory mechanisms (an aspect of executive function) are separate constructs whereby aging leads to a decrease in inhibition. This, in turn, leads to an increase in irrelevant information entering working memory and to a subsequent inability to distinguish that which is relevant from that which is irrelevant for the purposes of meeting one's long-term memory goals. Therefore, it is hypothesized that the influence of working memory on verbal memory performance is secondary again, but this time to the influence of executive function:

> Hypothesis 7a: Working memory will mediate the relationship between executive function and verbal memory encoding (links f and g in Figure 1).

> Hypothesis 7b: Working memory will mediate the relationship between executive function and verbal memory retrieval (links n and o in Figure 2).

Summary and Additional Predictions

It is clear that there are many studies implicating frontal dysfunction in age-related memory decline (Parkin & Lawrence, 1994; Hanninen, Hallikainen, Koivisto, Partanen, Laasko, Riekkinen, Soininen, 1997) and these findings are consistent with the hypothesis that executive functioning abilities may mediate the relationship between age and some types of memory tasks. However, there are few studies that take processing speed and working memory into consideration when examining the role of executive functioning in age-related memory performance. Troyer et al., (1994) found the executive function variable to mediate 36% of the age-related variance in episodic memory performance in a sample of healthy older adults, but this study did not include processing speed and working memory in their account of the age-memory relationship. Nor has any other study to this author's knowledge investigated the way in which the mediators might relate to one another in the context of a single study attempting to predict age-related memory decline by examining the mechanisms through which age exerts its effects in a multivariate sense. The present study will examine the mediating effects of executive functioning along with those of processing speed and working memory in the relationship between age and verbal memory tasks (free recall and recognition), as well as between age and memory processes (encoding and retrieval), while also making predictions based on previous literature as to the nature of the relationships between these mediators. In summary, there exists theory and research to support each of the links in the proposed models of age-related memory decline. However, these relationships have not yet been examined simultaneously.

In addition, it might be helpful to entertain the possibility that a temporal dimension may impact the series of relationships examined here, such that executive function may be more strongly related to memory as age increases. This would suggest that processing speed declines with age before executive function. But what about the research suggesting that the frontal lobes are the first to decline with age? This notion is not universally accepted. In fact, based on her recent review of the literature, Greenwood (2001) concludes that the frontal lobes are not differentially and uniquely affected by age. This author indicates that much of the research documenting similar levels of age-related decline in other areas of the brain has gone largely ignored. Coupled with this is the recent evidence suggesting that older adults use compensatory mechanisms for the neurological changes they experience with age. In their review of the literature with respect to the relationship among age, memory and frontal lobe functioning, Craik and Grady (2002) discuss the idea that the older brain may become less differentiated in function; instead, brain areas that were not previously used in completing certain tasks in younger years are recruited to work in a compensatory fashion as the person gets older. In fact, it was in March of this year that these findings were used in support of a new proposed cognitive neuroscience model called HAROLD (hemispheric asymmetry reduction in older adults), suggesting that this is a general aging phenomenon not just specific to verbal recall (Cabeza, 2002). If this is the case, perhaps the older adult can compensate for their more specific losses of executive function tied to frontal lobe function. However, it is less likely that they can compensate for the *general* slowing that likely occurs throughout the central nervous system. In this case, we should expect to see executive function more strongly related to memory as age increases, and as the brain becomes more deteriorated and less able to compensate. It would be that the decline we see in executive function early on is a product of processing speed deficits, and that the direct influence of age on executive functions is compensated for until later in life when this compensation is no longer working. If this were the case, then we would expect to find that processing speed is an important mediator throughout age-related memory decline and that executive function is more important later in time. This hypothesized relationship is depicted in Figure 5 and is summarized below:

> Hypothesis 8: Executive function will be more strongly related to memory as age increases.

Finally, it is conceivable that the importance of the mediators discussed here in the relationship between age and memory varies as a function of the intactness of the sample one is observing. More specifically, it is likely that there is variability in study samples identified as normal, healthy able elderly as to their level of functioning. It may be that executive function is a more important mediator of memory performance for those that exhibit preclinical levels of functioning. Consistent with this notion are DSM-IV criteria that include the decline of executive function in Alzheimer's Disease (AD), as impairment in central executive function has been identified in patients with the disease (e.g., Carlesimo, Fadda, Lorusso & Caltagirone, 1994; Morris, 1994) as compared to healthy individuals of the same age (Carlesimo, Mauri, Graceffa, Fadda, Loasses, Lorusso

& Caltagirone, 1998). This latter finding "supports the…position of a qualitative discontinuity between the physiological process of aging and the pathological condition underlying AD" (p. 26). Is it possible that processing speed is an important mediator for normal aging elderly and executive function is more important for those individuals who are abnormally aging? Perhaps executive function has been found to be an important mediator in the studies reviewed above because their "normal" aging samples include a subset of individuals who are in preclinical stages of a dementing process. For example, a recent study by Nathan, Wilkinson, Stammers and Low (2001) compared a group of mildly demented patients with age-matched nondemented controls and found that the mildly demented group performed significantly worse on many tests of executive function including the Stroop color word test and Trailmaking Parts A and B. These researchers concluded that these tests of frontal function can be used to distinguish subjects with mild dementia from their nondemented counterparts, albeit cautiously. If this were the case, then subjects' scores on a measure of global cognitive functioning that is frequently used as a dementia screener, the Mini-Mental Status Exam (MMSE), should moderate the relationship that both processing speed and executive function have with memory in the present study. The form of these putative relationships are depicted in Figure 6 and are summarized as follows:

> Hypothesis 9: A higher MMSE score will be associated with a stronger relationship between processing speed and memory. That is, processing speed should be more strongly related to memory function among intact individuals.
>
> Hypothesis 10: A lower MMSE score will be associated with a stronger relationship between executive function and memory. That is, executive function should be more strongly related to memory function among non-intact individuals.

METHOD

Participants

A total of 328 adults participated in this study ranging in age from 54-92 years (M = 70.37, SD = 8.2). All participants were community-dwelling elderly individuals recruited through local newspaper advertisements and talks given to local community groups. Exclusion criteria included self-reported levels of depression (as measured by the Beck Depression Inventory [BDI; Beck & Beck, 1972] and the Geriatric Depression Scale [GDS; Brink et al., 1982]); those individuals with significant levels of depression (scores of 30 or higher on the BDI and/or 20 of higher on the GDS) were excluded from the sample. In addition, the Mini-Mental Status Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was used as a screening measure for cognitive functioning associated with dementia; only subjects scoring above the standard cutoff of 24 points were included in the final sample. Finally, participants were screened for self-reported history of severe neurological or medical problems likely to affect their cognitive performance (e.g., stroke, terminal illness, traumatic brain injury, etc.). This was to ensure that the sample was representative of the normal aging population. Given the exclusionary criteria, the actual sample size used in the data analyses was 304 with participants ranging in age from 54-92 years (M = 70.0, SD = 8.1). There were 169 females, and the mean education of the sample was 15.7 years (SD = 3.0).

Procedure

Collection of the data used for this study was part of a larger program of research designed to assess the relationship between mood and memory in older adults. Participants were individually administered a battery of tests aimed at assessing their mood and cognitive abilities in a session of 90-120 minutes, and they were unaware of the hypotheses of the study. Testers were graduate students enrolled in the clinical doctoral program at MSU who had been trained to administer and score the tests in the battery. For the purposes of this study, only results from measures of executive functioning, processing speed, working memory, and verbal memory were analyzed and reported. Other relevant background information was also gathered at the time of testing, including participants' estimated VIQ (determined by the number of errors on the American version of the National Adult Reading Test [AMNART; Gober & Sliwinski, 1991] and years of education). Finally, each participant was offered the opportunity to participate in bi-weekly memory and attention training workshops as a result of participating in the study.

Measures

Screening

Beck Depression Inventory. (BDI; Beck& Beck, 1972): The BDI is a self-report measure consisting of 21 multiple-choice statements, each concerned with a particular depressive symptom. The subject is asked to rate their experience on a scale of graded severity. The total score for this test is determined by adding the highest number circled for each of the 21 items; the maximum score is 63. Higher scores indicate higher levels of depression. The authors of this test identified the following cutoff scores: 0-9 = normal; 10-15 = mild depression; 16-19 = mild/moderate depression; 20-29 = moderate/severe depression; 30+ = severe depression (Spreen & Strauss, 1998).

There is an extensive amount of psychometric data for the BDI. The authors of this test reported a test-retest reliability estimate above .90 (Beck, 1970). Other research has revealed a Spearman-Brown reliability estimate of .93 and an inter-item internal consistency estimate in the .80s (Reynolds & Gould, 1981; Steer et al., 1989). In addition, correlations among the BDI and other construct-valid measures of depression such as the MMPI Depression Scale (Reynolds & Gould, 1981), the Hamilton Rating Scale (Brown, Schulberg & Madonia, 1995) and clinical ratings of depression (Schaefer, Brown & Watson, 1985) have been reported to be substantial: .75, .85 and .66, respectively.

Geriatric Depression Scale. (GDS; Yesavage, Brink, Rose, Lum, Huang, Adey & Leirer, 1983): The GDS is a 30-item yes/no paper and pencil test in which the directionality of scoring changes randomly. This test was developed specifically for use with older adults and, therefore, does not include items that focus on issues the authors found to be less relevant to an aging population (e.g. guilt, sexuality and suicide). Alternatively, it does, however, include somatic items which are thought to be more applicable to older populations (Spreen & Strauss, 1998). The total score for this test is calculated by adding the point values assigned to each response with the following cutoff scores identifying varying levels of depressive symptomotology: 0-9 = normal; 10-19 = mild depression; 20-30 = moderate/severe depression (Spreen & Strauss, 1998).

The GDS is highly internally consistent ($\alpha = .94$; Koenig et al., 1988) and it is highly correlated with other self-report measures of depression including the Beck Depression Inventory (Beck & Beck, 1972; $r = .73$), the MMPI Depression Scale (Bielauskas & Lamberty, 1992; $r = .72$), the DSM-based Symptom Checklist for Major Depressive Disorders (Bielauskas & Lamberty, 1992; $r = .77$) and the Hamilton Depression Scale (Hamilton, 1967; $r = .83$) (Yesavage, Brink, Rose & Adey, 1986).

Factor analyses revealed a major factor of dysphoria (unhappiness, dissatisfaction with life, emptiness, downheartedness, worthlessness and helplessness). In addition, two smaller factors were revealed: one of worry, dread and obsessive thought and the other one of apathy and withdrawal (Parmelee, Lawton, & Katz, 1989). Criterion validity measured against the Research Diagnostic Criteria is .82 (Yesavage et al., 1983).

Mini Mental Status Exam. (MMSE; Folstein et al., 1975): The MMSE was developed as a primary measure of orientation to be used in assessments of cognitive functioning. However, the items on this test also measure memory ability, visuospatial functioning, written expression and the ability to follow simple commands. It is commonly used as a screener for dementia. The test consisted of 30 items; a cutoff score of 24 is recommended with most populations (Lezak, 1995).

Test-retest reliabilities for this test over a 24-hour period were .85-.99. In another population test-retest reliability over a two year period was .38, suggesting that the assessed abilities are somewhat unstable over time. Inter-rater reliability has been shown to be above .65 (Foster et al., 1988). In addition, performance on the MMSE correlates with both the Verbal ($r = .39$) and Performance ($r = .30$) IQ scores of the Wechsler Adult Intelligence Scale-Revised, providing some convergent validity evidence for this test (Mitrushina & Satz, 1991). In fact, this test has been shown to correlate not only with measures of general intelligence, but also with measures of memory, attention and concentration and executive functions (Axelrod et al., 1992). According to Spreen & Strauss (1998) studies show that the MMSE has adequate specificity and sensitivity for detecting dementia especially in cases of moderate to severe forms of impairment. Norms for the MMSE by age (18-85) and education based on a sample size of more than 18,000 have been published by Crum et al. (1993).

The following section describes the measures used to assess the main variables of interest in this study, organized by theoretical construct. A listing of the indicators for each construct is provided in Table 2.

Processing Speed (PS)

Two measures of processing speed were used in this study. The Symbol Digit Modalities Test (SDMT; Smith, 1991) is a timed test with both written and verbal components. In the written portion of the test the subject is asked to write numbers in empty boxes situated below boxes with various nonsense syllables. The correct number to be recorded is determined by the subject's use of a key (pairing each of the nine nonsense geometrical figures with the numbers one through nine) presented at the top of the page. In the oral portion of the test, the correct numbers are recorded by the examiner as the examinee calls them aloud. The subject is given 90 seconds for each portion of the test. The score obtained from this test is the number of correctly "substituted" numbers in each portion of the test with a maximum score of 110 on each.

The SDMT is described as a test of "visual scanning, tracking, and motoric speed" (Spreen & Strauss, 1998). As reported by Spreen & Strauss (1998), out of a collection of tests thought to measure speed of information processing, Ponsford and Kinsella (1992) found the oral version of the SDMT to be the most sensitive measure of a reduced speed of processing. Validity evidence for the SDMT includes observed positive correlations between its score and scores on other tests of processing speed such as the Coding subtest of the Wechsler Intelligence Scale for Children-Revised ($r = .62$) and the Digit Symbol subtest of the WAIS-R ($r = .73$-$.91$). Test-retest reliability correlations have been reported to be .80 (written portion) and .76 (oral portion; Spreen & Strauss, 1998).

Working Memory (WM)

WM will be assessed through use of the WMS-R Backward Digit Span (DSpB) And The WMS-R Visual Memory Backward Span (VMSpB) subtests (Wechsler, 1987).

Wechsler Memory Scale – Revised Digit Span Backwards. (DSpB): The DSpB involves presenting increasingly longer strings of numbers (from 2-8) and asking the subjects to repeat numbers in reverse order, thus requiring a large degree of mental manipulation of stimuli presented. As Lezak (1995) reports, "The reversed digit span requirement of storing a few data bits briefly while juggling them around mentally is an effortful activity that calls upon the working memory, as distinct from the more passive span of apprehension measured by Digits Forward" (p. 367).

Wechsler Memory Scale – Revised Visual Memory Span Backwards. (VMSpB): The VMSpB is the visual-spatial analog to DSpB. It assess visual working memory. The examiner taps a sequence of colored blocks and participants are required to tap the sequence in the reverse order.

Executive Function (EF)

EF was assessed by three different measures: The Stroop Color and Word Test (ST; Golden, 1978), the Wisconsin Card Sorting Test (WCST; Heaton, 1981), and the Trailmaking Test (TMT; Reitan, 1958).

The Stroop Color and Word Test. (Stroop; Golden, 1978): The Stroop consists of one reading and two naming trials. The reading trial requires the naming of words (either "blue", "red", "green", or "yellow") printed in black ink in columns of 20 words with five columns on the page. The first naming trial requires the naming of the color in which a group of four "x"s is printed. These groups of colored "x"s are also in the same format as the words in the reading trial. Finally, the second naming trial requires the naming of color when the name of a color is printed in a color that is different from the actual word itself. This second naming trial is the "interference" condition because the color spelled by the word interferes with the subject's ability to nae the color the word is printed in.

Scores on this test indicate the decrease in color-naming, which is called the "color-word interference effect" or the Stroop effect. The Stroop effect is the phenomenon that occurs with increasing errors and decreasing numbers of items correctly identified in the colored word list as compared to the first two lists. Performance is assessed by the time required to complete each naming trial and the difference between the interference condition and the simple naming of color dots; as stated above, this score is called the interference effect (Lezak, 1995; Spreen & Strauss, 1998).

The Stroop is thought to measure the degree to which participants are able to ignore competing but irrelevant information. It requires the subject to be able to consciously disregard the actual word and concentrate on the color in which the word is printed (Moscovitch & Winocur, 1995). The test has also been described as a measure of the degree to which individuals are able to shift their attentional resources and response inhibition (Spreen & Strauss, 1998). Validity evidence for the Stroop as a measure of frontal lobe function includes observed high correlations with other tests of frontal lobe functioning (verbal fluency test, $r = .58$ and a version of the Tower of London, $r = .65$; Spreen & Strauss, 1998). Overall reliability for this test is reported to be "satisfactory" (Lezak, 1995). Test-retest reliabilities reported by Spreen and Strauss (1998) range from .83-.91 for the three portions of the test.

Wisconsin Card Sorting Test. (WCST; Heaton, 1981): The WCST is a test that requires the participant to sort up to 128 consecutive cards. On each card one to four symbols are printed in one of four colors, under one of four stimulus key cards. The participant must deduce from the examiner's feedback (i.e. saying "correct" or "incorrect" after each response) the correct principle determining how the cards should be sorted at any given point of time during the test. The WCST is a test of set-shifting because the rule changes each time the participant sorts 10 cards correctly. This change is not conveyed to the participant; rather, it must be deduced from the "correct" or "incorrect" response provided by the examiner, and the participant's response strategy must be modified as a result. The principles by which the cards can be sorted include geometric form, color, or number of symbols.

The full, 128-card version with six categories was administered in this study, and performance was assessed by the total number of perseverative errors. Those errors identified as perseverative were in accordance with Heaton's (1981) criteria: 1) a response in Categories 2-6 that would have been correct in the immediately preceding category; 2) repetitions of the first incorrect unambiguous response in Stage 1 (before the first category is completed); and 3) repetitions of any response after three successive incorrect, unambiguous matches involving that response.

This test is thought to measure one's ability to set-shift, to maintain set, to successfully use corrective feedback, and to form abstract conceptual understanding (Spreen & Strauss, 1998). It has also been described by Moscovitch and Winocur (1995) as a measure of hypothesis formation and set-shifting and by Arnett and colleages (1994) as a measure of concept formation processes and inhibition of inappropriate responses, operations thought to be controlled by the frontal lobes of the brain. Validity evidence for this test as a measure of frontal lobe functioning includes research indicating that individuals with prefrontal lesions tend to display highly perseverative responses on this test (Milner, 1964; Heaton, 1981; Anderson, Jones, Tranel, Tranel, & Damasio, 1990). In addition, neuro-imaging research also provides evidence that the WCST is a measure of frontal lobe function. Specifically, magnetic resonance imaging (MRI) studies have found that the volume of the dorsolateral prefrontal cortex is significantly correlated with the number of perseverative error made on the WCST in normal young and older adults (Raz et al., 1995; Raz, Head, Gunning, & Acker, 1996). In addition, a study using SPECT scan technology found the WCST task to be associated with activation of the left dorsolateral prefrontal cortex (Rezai et al., 1993). Finally, PET findings also indicate that performance on the WCST is associated with frontal lobe functioning (Berman et al., 1995). Both intrascorer and interscorer reliability estimates are very impressive ranging from .88 to .96 (Lezak, 1995).

Trailmaking Test. (TMT; Reitan, 1958): The TMT consists of two parts, A and B. Trails A requires the drawing of a line to connect numbered circles in chronological order. Trails B requires the drawing of a line to connect numbered and lettered circles in interchanging chronological and alphabetical order. Thus, the test taker must draw a line from 1 to A, A to 2, 2 to B, and so on. On both parts of this test, mistakes made by the subject concerning the order of circles are corrected by the examiner.

The TMT will be calculated as the difference in time required to complete Trials B and A. This represents cognitive processing time (B) minus psychomotor speed (A). In other words, the difference score allows one to assess the cognitive processes underlying performance by controlling for psychomotor speed required in performing the task (Hanninen et al., 1997). This should help reduce the amount of overlap that inevitably exists between measures in this area of research.

The TMT has been described as "an attention task with an interference component, involving visual scanning skills, set-shifting ability, and complex conceptual tracking" (Hanninen et al., 1997). There is substantial validity evidence suggesting that this test is also a measure of frontal lobe functioning (Reitan, 1958; Picton et al., 1986). Reliability of the difference score is reported to be .71 (Lezak, 1995).

Verbal Memory

Performance in free-recall and recognition verbal memory, as well as memory encoding and retrieval process variables was assessed by the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987).

California Verbal Learning Test. (CVLT): The CVLT is a measure of verbal learning and memory consisting of five oral presentations of a list of 16 shopping items (Monday's list) followed by periods of free-recall. This is followed by one oral presentation of a second, interference, list of 16 shopping items (Tuesday's list) and a another period of free-recall. The 16 items on each list belong to four different categories. Immediately after the presentation and free-recall of Tuesday's list, the subject is asked to recall all of the items from Monday's list in a period of free-recall as well as in a period of cued-category recall (Short Delay). This same procedure is undertaken 20 minutes later (Long Delay). Finally, a recognition trial is completed involving the oral presentation of 44 shopping items where the objective is the successful

identification of the items on Monday's list. There are no time limits on any aspect of this test. Test words are presented verbally one word per second.

In terms of memory *tasks,* because the correlations between the three obtained scores of free-recall performance on this test (the average free-recall of the first five trials, the short-delay free-recall and the long-delay free-recall) were positive and significant, a composite score that combined these three scores was used as an overall indicator of free-recall memory performance. This composite was calculated by converting each of these scores to z-scores and summing them resulting in a single composite measure of free-recall memory performance. Recognition memory performance was indicated by the Recognition Discriminability index, which takes into consideration both hits and false positives. The CVLT manual describes it as "the single best measures of overall recognition performance" (Delis et al., 1987, p. 32).

In terms of memory *processes*, The CVLT was actually designed to provide information about a number of different verbal learning and memory processes (Delis et al., 1987). Retrieval was indicated by subjects' recognition-recall discrepancy scores. The combination of a relatively good recognition and poor recall performance is thought to indicate deficits in memory retrieval (Delis et al., 1987; Lezak, 1995), and these retrieval deficits are thought to occur along a continuum of severity (Duchnick, Vanderploeg & Curtiss, 2002). Following in the same footsteps as leaders in the field of neuropsychology, encoding was defined as "the ability to impose and use an effective semantic strategy to encode information during learning" (Curtiss, Vanderploeg, Spencer & Salazar, 2001, p. 576). It was operationally defined as a subject's semantic clustering score, a measure of the individual's ability to use effective learning strategies to encode new information; in this case, to categorize the 16 words into the four semantic categories they fall under. This operationalization of encoding was also used by Curtiss and colleagues (2001).

Reliability analyses of this test's normative sample was reasonable ($\alpha = .74$; Delis, Freeland, Kramer & Kaplan, 1988). The test-retest reliability in a sample of older adults with a one-year interval between administrations was .76 and .64 (Paolo, Troster & Ryan, 1997b and Cellucci et al., 2001, respectively). The correlations between the CVLT and other tests purporting to measure the intended construct are said to be modest (Lezak, 1995). Exploratory factor-analytic work has revealed a six-factor solution for normal subjects that includes the following: 1) General Verbal Learning factor; 2) Response Discrimination factor (loadings in free recall intrusions, cued recall intrusions and false positives); 3) Learning Strategy factor; 4) Proactive Effect factor; 5) Serial Position effect; 6) Acquisition Rate (Delis et al., 1988). Thus, the CVLT has greatly enhanced our ability to measure verbal learning and memory as compared to earlier tests of this aspect of cognition which for the most part produce a single General Verbal Learning and Memory factor (Delis et al., 1988).

DATA ANALYSIS

The empirical accuracy of the proposed neuropsychological models of normal cognitive aging were examined with structural equation modeling (SEM) using the maximum likelihood method in LISREL 8 (Joreskog & Sörbom, 1993) to estimate the parameters in the models (factors loadings, path coefficients, error variances, correlations). This pertains to Hypotheses 1-7, which are represented in the model by specific linkages in Figures 1 (encoding) 2 (retrieval), 3 (recall), and 4 (recognition). SEM provides a clearer understanding of the multivariate relationships among key constructs in this area of research as compared to the multiple regression analyses that have dominated much of the extant literature. Specifically, SEM provides a more easily understandable account of the relative contributions of different pathways to the behavior of interest; that is, all of the relationships can be tested simultaneously rather than testing numerous bivariate relationships. In addition, it corrects for measurement error in the observed variables. Given that the psychological tests used in this study have less than perfect reliability, this is a very important benefit of using SEM, and it will ultimately provide better estimates of the theoretical relationships of interest. Finally, it allows for the simultaneous evaluation of competing theoretical models, enabling one to determine the fit of the model to the entire set of covariances among study variables (Ferrer-Caja et al., 2002; Hultsch et al., 1998).

RESULTS

Estimation and Imputation of Data

Means, standard deviations and intercorrelations (using pairwise deletion) among all study variables appear in Table 3. The listwise N was 222. In order to prevent bias associated with deleting cases for which there was missing data, and to maximize power, it was decided to estimate missing data via imputation. Using Schafer's (1997) method of multiple imputation, missing data were estimated for all study variables except for total score on the Beck Depression Inventory-2 (BDI-2). Scores on this variable were not imputed because there was either too much missing data or the pattern of missing data when all of the variables were run was such that the program could not impute the missing values in the dataset. Given that only .7% of subjects in the sample had elevated depression scores on the BDI-2, in combination with the fact that the Geriatric Depression Scale (GDS), the second measure of depression, is specifically designed for use with an older adult population, those cases with missing BDI-2 values that were unable to be imputed were retained. After estimation and imputation there were 304 subjects in the dataset.

Descriptive Statistics and Intercorrelations

Means and standard deviations of sample descriptives, including age, years of education, estimated verbal intelligence quotient (VIQ), MMSE, GDS and BDI scores are displayed in Table 4. Means, standard deviations and correlations among the key study variables after imputation are presented in Table 5 (N = 304). Compared to the observed pairwise correlation matrix before imputation of data (Table 3), the correlations after imputation (Table 5) are slightly higher on average, but overall, the correlation matrices are very similar.

Age and Study Variables

As predicted, age was correlated negatively, but only modestly, with measures of memory recall ($r = -.29$, $p < .01$), recognition ($r = -.22$, $p < .01$) and memory retrieval ($r = -.24$, $p < .01$). Surprising, however, was that age was not significantly related to memory encoding ($r = .11$, $p > .05$). Age was negatively correlated with working memory as measured by the Backwards Digit Span of the WAIS-R (DSpB; $r = -.20$, $p < .01$) and the Backwards Visual Memory Span of the WAIS-R (VSpB; $r = -.23$, $p < .01$). Age was also negatively related to processing speed as measured by both the written ($r = -.56$, $p < .01$) and oral ($r = -.54$, $p < .01$) forms of Symbol Digit Modality Test (SDMT). Finally, age was negatively correlated with all three of the executive function measures, including the Trailmaking Test (TMT; $r = -.36$, $p < .01$), the Stroop Test (ST; $r = -.30$, $p < .01$), and the Wisconsin Card Sorting Test (WCST; $r = -.31$, $p < .01$). Overall, age was negatively and moderately associated with all study variables as expected with the exception of verbal memory encoding. A decline in speed of processing was the most highly associated with advancing age, followed by executive function, recall memory, memory retrieval, memory recognition and working memory.

Memory Encoding and Study Variables

Also shown in Table 5, the measure of memory encoding was not associated with any of the study variables except a modest association with the number of perseverative errors on the WCST ($r = .12$, $p < .05$), such that higher performance was associated with better memory encoding.

Memory Retrieval and Study Variables

Table 5 also indicates that the measure of memory retrieval was positively associated with both measures of working memory (DSpB $r = .13$, $p < .01$; VSpB $r = .11$, $p < .01$). However, with respect to the mediators of interest, memory retrieval was most strongly related to measures of processing speed (DSMT written $r = .26$, $p < .01$; DSMT oral $r = .33$, $p < .01$) such that faster processing was associated with better retrieval. Finally, all measures of executive function were related to memory retrieval, including the TMT ($r = .20$, $p < .01$) the ST ($r = .16$, $p < .01$) and the WCST ($r = .19$, $p < .01$), such that higher performance was associated with better memory retrieval. Thus, overall, there was a striking difference between memory encoding and memory retrieval with respect to the magnitude of their respective relationships with the three mediators, with memory encoding only related to one measure of executive function and memory retrieval related to all three mediators in the following order of magnitude: processing speed, executive function and working memory.

Structural Equation Modeling (SEM)

To examine the hypothesized relationships between the study variables in a multivariate sense, the conceptual models presented in Figures 3 and 4 (Hypothesis 1), as well as the models presented in Figures 1 and 2 (Hypotheses 2-7), were tested using structural equation modeling. All the hypothesized paths in the model were derived from the theory and research used to formulate the first seven study hypotheses. Evidence for the mediated effects was tested by examining the significance and size of the indirect effects and by examining comparison models described below.

General Background Information

As stated earlier, multiple indicators were used to assess the latent variables in the structural models represented in Figures 1 thru 4 when possible. Study constructs and the corresponding indicator variables are presented in Table 2. Two indicators per latent construct were used for working memory (DSpB; VSpB) and processing speed (DSMT-written; DSMT-oral). Three indicators were used for executive function (TMT; ST; WCST) and one indicator was used for each of the dependent variables: verbal memory recall (CVLT-FR), recognition (CVLT-RD), encoding (CVLT-SCR) and verbal memory retrieval (CVLT-FR/RD). The relationships in the hypothesized models were tested directly and, in a multivariate sense, corrected for measurement error due to internal consistency unreliability using SEM.

As can be seen in the table, there were single indicator variables for age, memory tasks (recall and recognition), and memory processes (encoding and retrieval). Because age was measured without error, the error variance of this variable was set to zero in LISREL; however, the reliabilities of the other four dependent variables were likely to be less than perfect, though unknown. Consequently, additional models were run where the reliability of these variables was set to .80. This value was chosen because it represents what might be expected as a lower threshold for the reliability of a well-developed and well-researched measure used for individual assessment such as the CVLT (e.g., the alpha for free-recall in the first five trials was reported to be .86 by Van der Linden et al., 1999). This was implemented in LISREL by setting the factor loading at the square root of the reliability, and by setting the error variance of the indicator as 1 minus the square root of the reliability times the indicator's variance. These alternative models yielded completely standardized path coefficients that were virtually identical to the ones discussed in detail below. Thus, the final models were run with the variables assigned a perfect reliability, which is the most conservative approach, but also one that yields results that are nearly identical to those with more realistic reliability estimates.

As indicated above, LISREL 8 (Jöreskog & Sörbom, 1993) was used to evaluate the fit of the data to the conceptual models in Figures 1 thru 4. The measurement and structural models were analyzed simultaneously. The measurement model displays the form of the relationships between the observed indicator variables with their latent constructs though the measurement error associated with each of these indicators is omitted from the figures to reduce clutter. The structural model displays the form of the relationships among the latent constructs themselves. Model fit was assessed by examining the chi-square (χ^2) statistic and a variety of practical fit indices. The χ^2 statistic is the most widely used measure of model fit, indicating whether a model is consistent with the covariances seen among the observed variables; however, relying on multiple indices of fit is usually recommended. In the present study, the additional indices used include Jöreskog and Sörbom's (1989) goodness-of-fit index (GFI) and adjusted goodness-of-fit index (AGFI), Bentler's (1990) comparative fit index (CFI), Bentler's and Bonett's (1980) nonnormed fit index (NNFI), Jöreskog and Sörbom's (1986) standardized root mean square residual (standardized SRMR) and Steiger's (1990) root mean square error of approximation (RMSEA).

The values of GFI, AGFI, CFI and NNFI represent a model's ability to accurately reproduce all of the covariances. They range from 0 to 1.0 with values approaching 1.0 indicating a good fit to the data. The present study used the widely accepted convention of .90 or above as an indication of good fit. The SRMR is a measure of the average standardized difference between the predicted and observed covariance matrices (i.e., the model's inability to accurately reproduce all the covariances; Tabachnick & Fidell, 1996). Values less than .10 indicate a good fit to the data. The RMSEA is the average fitted residual per degree of freedom (Browne & Cudeck, 1993). The present study considered a value of .05 or less as indicating a close fit, between .05 and .10 as a moderate, or reasonable, fit, and finally, greater than .10 as a poor fit, as suggested by Browne and Cudeck (1993).

Recall vs. Recognition Memory: Hypothesis 1

Hypothesis 1 predicted that free-recall memory would rely on the mediating resources (processing speed, working memory and executive function) to a greater extent than would recognition memory. Represented schematically, this implies that links v, w and x in Figure 3 would be greater than links cc, ee and ff in Figure 4. Figures 7 and 8 present the full structural and measurement model with the completely standardized path coefficients and factor loadings for memory recall and memory recognition, respectively. The hypothesis was tentatively supported, as the difference between the sums of the path coefficients in the two models was relatively small (.08), and only the link between executive function and verbal memory recall was significant (link x).

Verbal Memory Encoding: Hypotheses 2a-7a

Figure 9 presents the full structural and measurement model along with the completely standardized path coefficients and factor loadings testing the hypotheses relating to verbal memory encoding. This model resulted in a good fit based on the fit indices $\chi^2 = 17.96$ ($df = 21$, $N = 304$, $p = .65$) GFI = .99, AGFI = .97, CFI = 1.00, NNFI =

1.00, SRMR = .03, and RMSEA = .00. As shown in Figure 9, all of the factor loadings were significant though some were relatively small, at least in confirmatory factor analytic terms. More specifically, the three measures of executive function and the two measures of working memory had relatively low factor loadings. This is consistent with the low intercorrelations among the three indicator variables for the executive function construct: r = .13 (Stroop and WCST); r = .22 (Stroop and Trails); r = .31 (WCST and Trails) and among the two indicator variables for the working memory construct: r = .28 (DSpB and VSpB). Examination of t-values revealed that the paths from processing speed to working memory and executive function were significant. In addition, the path from executive function to working memory was also significant. However, none of the paths from the hypothesized mediators (processing speed, executive function and working memory) to memory encoding were significant.

The modification indices and completely standardized expected changes for the factor loadings of the indicator variables on the mediating latent constructs were also very small (see Table 6). To explain more fully, the modification indices indicate by how much χ^2 would decrease (and thus model fit would improve) if factor loadings that were not estimated were in fact estimated. Similarly, the completely standardized expected change indicates what the factor loadings would be if the indicators were assigned to different constructs. Thus, these statistics suggest that evaluating alternative models with different indicators assigned to different constructs would not be fruitful, as all the factor loadings would be $\leq$ the absolute value of .25. This is consistent with the very modest intercorrelations among the indicator variables for the mediators discussed earlier (Table 5).

Table 7 restates Hypotheses 2a through 7a, indicates the corresponding link in the conceptual model, provides completely standardized path coefficients and also indicates which hypotheses were supported. In addition, where the mediational hypotheses were supported, the total effect from the first to the third variables in the causal chain is provided, which is simply the product of the two path coefficients. As the table indicates, Hypothesis 3 was supported; however, the size of the total effect was only small to moderate, at least in mediational terms.

In order to fully test the mediational influences of processing speed and executive function in the Baron and Kenney (1986) sense, however, this model must be compared to other models, including one model that has a path going from Age (the predictor) to Encoding (the criterion) and another model that excludes the path from Age (the predictor) to Processing Speed (the mediator in this example) while including the path from Age to Encoding. Comparison of these three models for both processing speed and executive function would allow for one to verify the hypothesized model in this study is, indeed, the most accurate model. More detail on these models is provided below. While there are many different mini-mediational models found within the overall model, it is only processing and executive function that will be tested in this sense because they are the only ones that are hypothesized to directly mediate the relationship between age and verbal memory, the main relationship of interest in this study.

Processing speed.

The model including a path from Age to Encoding is shown in Figure 10 and the model excluding a path from Age to Processing Speed while including a path from Age to Encoding is shown in Figure 11. The top section of Table 8 displays the comparison of the three models. Comparing the complete and mediational models (i.e., model two with model one), we see that the mediation model is significantly a better fitting model. This can be seen by the significant change in chi-square, as well as a slight though fairly consistent increase (decrease, in the case of RMSEA) in the practical fit indices. Comparing model three with model one we see that the no mediation model is significantly worse as indicated by the significant change in chi-square and the fit statistics that indicate an overall poor fit. This supports the proposed mediational influence of processing speed in the age-related decline of memory encoding in this study.

Executive function.

Again, the model including a path from Age to Encoding is shown in Figure 10. The model excluding a path from Age to Executive Function while including a path from Age to Encoding is shown in Figure 12. The bottom section of Table 8 displays the comparison of the three models. Comparing the complete and mediational models (i.e., model two with model one), we see that the mediation model is significantly a better fitting model. This can be seen by the significant change in chi-square, as well as a slight though fairly consistent increase (decrease, in the case of RMSEA) in the practical fit indices. Comparing model three with model one we see that the no mediation model is significantly worse as indicated by the significant change in chi-square and the fit statistics. This supports the proposed mediational influence of executive function in the age-related decline of memory encoding in this study.

Verbal Memory Retrieval: Hypotheses 2b-7b

Figure 13 presents the full structural and measurement model along with the completely standardized coefficients testing the hypotheses relating to verbal memory retrieval. This model resulted in a good fit as indicated by the fit indices $\chi^2 = 26.05$ (df = 21, N = 304, p = .20), GFI = .98, AGFI = .96, CFI = .99, NNFI = .99, SRMR = .03, and RMSEA = .03. As with the other model, and as shown in Figure 13, all of the factor loadings were significant though again some were quite small. This was fully expected given that this model is the same as that depicted in Figure 9 except that retrieval was substituted for encoding as the dependent variable. Examination of the t-values revealed that all paths from processing speed to working memory and executive function were significant. In addition, the path from executive function to working memory was also significant. However, none of the paths from the mediators (processing speed, executive function and working memory) to memory retrieval were significant. As discussed earlier, modification indices and completely standardized expected changes did not provide evidence that evaluating alternative measurement models would be fruitful (see Table 6).

Table 9 restates Hypotheses 2b through 7b, indicates the corresponding link in the conceptual model, provides completely standardized path coefficients and also indicates which hypotheses were supported. In addition, where the mediational hypotheses were supported, the total effect from the first to the third variables in the causal chain is provided, which is simply the product of the two path coefficients. Again, only the small to moderate effect corresponding to Hypothesis 3 was supported.

In order to fully test the mediational influences of processing speed and executive function in the Baron and Kenney (1986) sense, however, this model must also be compared to other models using the same general approach as described above. Briefly, these comparison models include one that has a path going from Age (the predictor) to Retrieval (the criterion) and another model that excludes the path from Age (the predictor) to Processing Speed (the mediator in this example) while including the path from Age to Retrieval. Comparison of these three models for both processing speed and executive function would allow for one to verify the hypothesized model in this study is, indeed, the most accurate model. Again, while there are many different mini-mediational models found within the overall model, it is only processing and executive function that will be tested in this sense because they are the only ones that are hypothesized to directly mediate the relationship between age and verbal memory, the main relationship of interest in this study.

Processing speed.

The model including a path from Age to Retrieval is shown in Figure 14 and the model excluding a path from Age to Processing Speed while including a path from Age to Memory is shown in Figure 15. The top section of Table 10 displays the comparison of the three models. Comparing model two with model one, we see that the mediation model is not a significantly better fitting model; instead, the fits are almost identical. Thus, we would choose the more parsimonious of the two as the best fitting model, which is the mediation only model hypothesized in this study. Comparing model three with model one we see that the no mediation model is significantly worse as indicated by the significant change in chi-square and the fit indices. This supports the proposed mediational influence of processing speed in the age-related decline of memory retrieval in this study.

Executive function.

Again, the model including a path from Age to Memory is shown in Figure 14. The model excluding a path from Age to Executive Function while including a path from Age to Memory is shown in Figure 16. The bottom section of Table 10 displays the comparison of the three models. Comparing model two with model one, we see that the mediation model is not a significantly better fitting model; instead, the fits are almost identical. Thus, we would choose the more parsimonious of the two as the best fitting model, which is the mediation only model hypothesized in this study. Comparing model three with model one we see that the no mediation model is significantly worse. This supports the proposed mediational influence of executive function in the age-related decline of memory retrieval in this study.

Moderated Regression

Composite scores.

To test the predictions of Hypotheses 8, 9 and 10, composite scores were formed. First, as shown in Table 11, correlations between four scores of free-recall and recognition memory performance as assessed by the CVLT were moderately large, positive and significant. Therefore, a composite score that combined the raw score performance of the first five trials, short-delay free-recall, long-delay free-recall and recognition hits on the CVLT was used as an overall indicator of memory performance by standardizing each of these scores and summing them. Second, recall from Table 5 that although the correlations between the three measures of executive functioning (TMT, ST, and WCST) were small, they were positive and significant. As a result, for the purposes of carrying out the proposed analyses, these scores were also standardized and summed to form a single composite measure. Finally, also shown in Table 5, the correlations between the two measures of processing speed (DSMT written and DSMT oral) were positive and significant. These scores were also converted to standardized scores and summed to form a single composite measure.

Hypothesis 8: Age X executive function

Hypothesis 8 suggested that Age and Executive Function would interact to predict overall memory performance. To ensure that the relationship between executive function and memory was not nonlinear, regression analyses were conducted where Executive Function was entered in the first step, followed by Executive Function squared in the second step. Memory was operationalized as a composite of both free-recall and recognition types of memory performance on the CVLT as described above. Table 12, which summarizes the results of these analyses, shows that the Executive Function, entered at the first step, accounted for a significant proportion of the variability in Memory ($\hat{\beta}$ = .30; overall step R^2 = .093, $p < .05$); however, the Executive Function squared term was not significant ($\hat{\beta}$ = .05; ΔR^2 = .002, $p > .05$). Thus, there was no evidence for a quadratic relationship between these two variables.

Hypothesis 8 was then tested using moderated regression where Age and Executive Function were entered in the first step, followed by the Age X Executive Function interaction term in the second step. Again, Memory was operationalized as a composite of both free-recall and recognition types of memory performance on the CVLT as described above. Table 13, which summarizes the results of these analyses, shows that the Age and Executive Function, entered at the first step, accounted for a significant proportion of the variability in Memory ($\hat{\beta}_{age} = -.18$; $\hat{\beta}_{executive\ function} = .22$; overall step $R^2 = .117$, all $p < .05$); however, the Age X Executive Function interaction term was not significant ($\hat{\beta} = -.25$; $\Delta R^2 = .001$, $p > .05$). Thus, Hypothesis 8 was not supported.

Hypothesis 9: MMSE X processing speed.

Recall that the Mini-Mental Status Examination (MMSE) was originally used as a dementia screener in the present study to ensure that the sample was representative of the normal aging population. Testing Hypotheses 9 and 10 required the examination of the full range of MMSE scores. Thus, while retaining this variable in the dataset, Schafer's (1997) method of multiple imputation was used again to estimate and impute missing data for all study variables, including the MMSE total score. All other original exclusionary criteria (e.g., scores above 20 on the Geriatric Depression Inventory) were still applied.

Hypothesis 9 suggested that MMSE and Processing Speed would interact to predict overall memory performance. To ensure that the relationship between processing speed and memory was not nonlinear, regression analyses were conducted where Processing Speed was entered in the first step, followed by Processing Speed squared in the second step. Table 14, which summarizes the results of these analyses, shows that the Processing Speed, entered at the first step, accounted for a significant proportion of the variability in Memory ($\hat{\beta} = .35$; overall step $R^2 = .123$, $p < .05$); however, the Processing

Speed squared term was not significant ($\hat{\beta}$ = .027; ΔR^2 = .001, p > .05). Thus, the relationship between these two variables is linear.

Hypothesis 9 was then tested using moderated regression where MMSE scores and Processing Speed were entered in the first step, followed by the MMSE X Processing Speed interaction term at the second step. Table 15, which summarizes the results of these analyses, shows that the MMSE scores and Processing Speed, entered at the first step, accounted for a significant proportion of the variability in Memory ($\hat{\beta}_{MMSE}$ = .21; $\hat{\beta}_{processing\ speed}$ = .35; overall step R^2 = .245, all p < .05); however, the MMSE X Processing Speed interaction term was not significant ($\hat{\beta}$ = -.01; ΔR^2 = .000, p > .05). Thus, Hypothesis 9 was not supported.

Hypothesis 10: MMSE X executive function.

Finally, Hypothesis 10 predicted that MMSE scores and Executive Function would interact to predict overall memory performance, and thus was also tested using moderated regression where MMSE and Executive Function were entered in the first step, followed by the MSME X Executive Function interaction term in the second step. Table 16, which summarizes the results of these analyses, shows that the MMSE scores and Executive Function, entered at the first step, accounted for a significant proportion of the variability in Memory ($\hat{\beta}_{MMSE}$ = .30; $\hat{\beta}_{executive\ function}$ = .23; overall step R^2 = .195, all p < .05); however, the Age X Executive Function interaction term was not significant ($\hat{\beta}$ = .-.42; ΔR^2 = .001, p > .05). Thus Hypothesis 10 was not supported.

DISCUSSION

This study sought to elucidate the mechanisms underlying the decline of memory with advancing age in a sample of community-dwelling older adults. More specifically, the mediating roles of working memory, processing speed and executive function in age-related memory decline were examined with respect to two memory tasks (free-recall and recognition) as well as two memory processes (encoding and retrieval).

Hypothesis 1: Recall (Figure 7) and Recognition (Figure 8) Models

Hypothesis 1 predicted that free-recall memory would rely on the mediating variables more than would recognition memory. Stated another way, this hypothesis predicted that links v, w and x in Figure 3 would be greater than links cc, ee and ff in Figure 4. The actual path coefficients are presented in Figures 7 and 8. This hypothesis received tentative support, as the only significant link was between executive function and free-recall memory. In addition, the sum of the path coefficients leading to free-recall from the mediators was greater, albeit only slightly, as compared to the sum of the path coefficients leading to recognition from the mediators. This is in line with previous theory (Moscovitch & Winocur, 1995) and research (Crawford et al, 2000; Ferrer-Caja et al., 2002; Park et al., 1996; Parkin & Lawrence, 1994; Parkin & Walter, 1991, 1992) suggesting that free-recall memory performance is more resource-intensive than mere recognition. Explanations for why the difference was not particularly robust in the present study will be addressed in the Methodological Considerations section below.

Hypotheses 2-7: Encoding (Figure 9) and Retrieval (Figure 13) Models

Hypotheses 2a through 7a and hypotheses 2b through 7a pertain to the development of the theoretical models displayed in Figures 1 (encoding) and 2 (retrieval), respectively. The results of structural equation modeling (SEM) analyses testing model fit for encoding and retrieval are displayed in Figures 9 and 13, respectively. When tested against alternative models per the ideas put forth by Barron and Kenny (1986), these mediational models of age-related memory decline were the best fitting models. However, while all the paths from age to the mediators and all the paths between the mediators themselves were significant, none of the paths from the mediators to the dependent variables (encoding in Figure 9 and retrieval in Figure 13) were significant.

Each hypothesis, all model links, path coefficients and total effects are listed in Tables 7 (encoding) and 9 (retrieval). These tables also indicate whether each hypothesis was supported. As can be seen in the Tables, only Hypothesis 3, which predicted that processing speed would mediate the relationship between age and working memory, was supported. The total effect was -.17, $p < .05$. This finding is particularly interesting given the contradictory findings in the literature with respect to these constructs. Specifically, while both Mayr and Kliegl (1993) and Nettelbeck and Rabbitt (1992) found processing speed and working memory both independently mediated the relationship between age and memory, other research is consistent with the findings of the present study, indicating that instead of a direct effect of age on working memory, the relationship between age and working memory is at least partially mediated by processing speed (Fisk & Warr, 1996; Hultsch et al., 1998; Park et al., 1996; Salthouse, 1992a; Salthouse & Babcock, 1991; Van der Linden et al., 1999). This is consistent with the idea that working memory is actually a secondary mediator (impacting by slowed information processing) in the relationship between age and memory.

The fact that none of the paths to the dependent variables were significant was unexpected, however, and suggests that a large proportion of variance in age-related cognitive decline may be shared among the mediators (Salthouse et al., 1996; Salthouse & Czaja, 2000). This is the basic idea behind the common cause model of cognitive aging, which posits that age influences one causal factor that, in turn, impacts a number of variables, including cognitive abilities, but also sensory and motor function (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994). Thus, additional analyses were conducted using SEM testing the models presented in Figures 17 and 18. These figures were developed based on the common-cause perspective, which again, is an alternative theoretical orientation to the one used as the basis for the research reported here. In these models, age predicts the common cause construct which is conceptualized as a second-order construct composed of processing speed, working memory, executive function and memory. That is, these are hierarchical models with age exerting its effects at the highest level (the level of the common cause), which in turn causes age-related deterioration of various cognitive abilities, including the memory processes measured here (Salthouse & Czaja, 2000).

Figures 19 and 20 present the full structural and measurement model along with the completely standardized path coefficients and factor loadings. The model for encoding resulted in a poor fit based on the fit indices $\chi^2 = 1150.81$ (df = 28, N = 304, $\underline{p}$ = .00) GFI = .85, AGFI = .76, CFI = 0.0, NNFI = -.76, SRMR = .16, and RMSEA = .13. Examination of $\underline{t}$-values revealed that the paths from the common cause construct to all three variables (processing speed, working memory and executive function) were significant; however, the path from common cause to encoding was not. The model for retrieval, however, resulted in a good fit based on the fit indices $\chi^2 = 44.28$ (df = 28, N = 304, p = .03) GFI = .97, AGFI = .95, CFI = .98, NNFI = .98, SRMR = .06, and RMSEA = .04. As can be seen in the figure, the factor loadings of the mediators onto the common cause construct are all very high (the average is 86.3), suggesting that a single higher-order construct explains much of the shared variance among the three proposed mediators. Examination of t-values revealed that the paths from the common cause construct to all three variables (processing speed, working memory and executive function) were significant. In addition, the path from common cause to retrieval was also significant.

This is consistent with the recent findings of Salthouse and Czaja (2000) and Salthouse (2001) that indicate the superiority of a hierarchical model of cognitive aging as compared to other commonly investigated models of age-related cognitive decline. As these authors describe, this kind of a model indicates "that a large proportion of the age-related effects on the variables operate at a high level...and, consequently, are shared among all variables at lower levels" (p. 49). These authors found that the addition of a higher order factor improved model fit to their data. Table 17 compares the common cause model for retrieval with the mediational model proposed in this study. The change in χ^2 between the models is significant, but only marginally so. The other fit indices suggest that the models fit similarly well. In combination with the fact that the common cause construct was significantly related to the dependent variable in this study, unlike the mediators of interest, adoption of the more parsimonious common cause model seems warranted.

However, it seems important to test this model against an even more parsimonious model where age simply predicts decline in all of these cognitive variables directly (see Figure 21). Table 18 displays a comparison of the Common Cause Model and a model in which age directly predicts all of the cognitive variables. Since the degrees of the freedom are the same for each model, comparison of their χ^2 values is not possible. However, it is apparent that the age model provides an overall poor fit, that the common cause model fits relatively well, and thus should be accepted as a more appropriate model.

Though providing better fit empirically, the theoretical nature of this higher order factor is not entirely clear. Salthouse and Czaja (2000) suggest two alternatives – that it's either: 1) a decline in a cognitive process (e.g., processing speed) or 2) decreased functioning of a particular neurological structure or neurotransmitter system. Salthouse (2001) found that reasoning ability was the most strongly related cognitive variable to the higher-order factor and thus suggested the importance of Horn and Cattell's fluid intelligence model to explain age-related cognitive decline. The fact that the hierarchical model more accurately described the data in the present study suggests that the current trend towards investigating the nature and anatomical correlates of the common cause is warranted.

Alternative explanations for the fact that none of the links to the dependent variables were significant even though all of the other links in the model were significant might also be explained by the attenuation of correlations in this study due to small variances in age and the performance measures used in this study. In addition, the reliability of the measures used, though satisfactory, is certainly not perfect. Although

SEM can correct for some degree of measurement error, imperfect reliability could have still attenuated the correlations in this study. These methodological limitations are discussed and further elaborated upon in a later section.

Hypothesis 8: Age x Executive Function as a Mediator of Memory

Hypothesis 8 predicted that executive function might be more strongly related to memory as age increases (represented schematically in Figure 5). This was based on recent claims that the frontal lobes are not the first areas of the brain to decline to age (Greenwood, 2001), and recent neuroimaging findings suggesting that the older brain may be able to compensate for losses in frontal function (Cabeza, 2002; Craik & Grady, 2002). However, support was not found for this hypothesis. While both age and executive function when entered separately predicted memory performance, the interaction term did not. This is not entirely surprising. Recall that there is a great deal of research that suggests executive/frontal function does decline early in the aging process (Albert & Kaplan, 1980; Diagneault et al., 1992; Fabiani et al., 1998; Ragland et al., 1997; West, 2000), and it may be that the compensatory mechanisms reflected in the neuroimaging studies involve frontal lobe functions that are less important for memory performance.

Hypotheses 9 and 10: MMSE x Executive Function/Processing Speed as Mediators of Memory

Hypothesis 9 predicted that processing speed would be more strongly related to memory function among intact individuals (those scoring higher than 24 on the MMSE, a dementia screener) and Hypothesis 10 predicted that executive function would be more strongly related to memory function among non-intact individuals (those scoring 24 or less on the MMSE). These predictions were based on the fact that impairment in central executive function has been identified in patients with Alzheimer's Disease (e.g., Carlesimo et al., 1994; Morris, 1994) as compared to healthy individuals of the same age (Carlesimo et al., 1998), and evidence that tests of executive function have been used to identify early stages of dementia (Nathan et al., 2001). The form of these predictions is displayed in Figure 6. However, neither of these hypotheses were supported in the present study. While MMSE scores, processing speed and executive function all independently predicted memory performance, the interaction terms did not. This is also not entirely surprising, as a decline in executive function has been demonstrated in normal aging populations (Haaland et al., 1987; Mittenberg et al., 1989; Nielson et al., 2002; Whelihan & Lesher, 1985). It may be that it simply worsens when cognitive decline becomes clinically significant, or that the nature of the executive decline differs between intact and non-intact samples. Analysis of this hypothesis would require a more precise differentiation and understanding of the individual cognitive abilities comprised under the more general term of executive function.

Unexpected Findings

Memory encoding. An unexpected finding was that memory encoding was not related to age or the other study variables in the present sample. This is inconsistent with a long line of theory (Craik & Lockhart, 1972; dellaRocchetta, 1986; Hasher & Zacks, 1988; Light 1991; Moscovitch, 1989, 1992, 1995; Poon, 1985; Salthouse, 1991, 1996; Stuss et al., 1982) and research (Bryan et al., 1999; Kliegl et al., 1989; Stebbins et al., 2002; Verhaeghen et al., 1992; see Craik & Grady, 2002 for a review of the neuroimaging literature), and might be due to the definition and operationalization of the encoding construct, defined as "the ability to impose and use an effective semantic strategy to encode information during learning" (Curtiss, Vanderploeg, Spencer & Salazar, 2001, p. 576). It was operationally defined as a subject's semantic clustering score on the CVLT, a measure of the subject's ability to use effective learning strategies to encode new information; in this case, to categorize 16 words into the four semantic categories they fall under. Thus, this measures the degree to which a subject implements an encoding strategy known to be optimal for list learning, which should theoretically lead to better encoding. This is the operationalization used by leading researchers in the field when investigating encoding processes in a head injured population (Curtiss et al., 2001); however, it is possible that implementing this kind of an encoding strategy might actually impede performance in an older adult sample. Recall that age differences in encoding often increase, as compared to decrease, when optimal encoding strategies are used (Kliegl et al., 1989; Light, 1991; Verhaeghen et al., 1992). It may be that older adults are not only unable to benefit from the use of such strategies, their encoding may even be hindered by it.

Part of the issue is the theoretical need to distinguish between encoding and recognition memory. One might argue that a good measure of encoding on the CVLT is the Recognition Discriminability index; that is, if a subject can accurately identify all the words on the list, he or she must have effectively encoded the information (Delis et al., 1987). However, this index is also described as the single best indicator of recognition on the CVLT (Delis et al., 1987), and was therefore used in the present study as an indicator of recognition memory. If one were to blur the theoretical boundary between encoding and recognition (which was found to correlate with age and other study variables in the present study), then one could discuss encoding as operationalized by a subject's ability to discriminately identify words on the list (i.e. Recognition Discriminability index). In the present study, that would allow for the comparison of encoding and retrieval processes with respect to how greatly they are influenced by the mediating constructs of interest. In that case, simply examining the correlation matrix presented in Table 5 allows one to observe several things, including the fact that there is not a appreciable difference between the correlations among retrieval and the mediating variable indicators (processing speed $\underline{r}$ = .26, .33; working memory $\underline{r}$ = .13, .11; executive function $\underline{r}$ = .20, .16, .19) and the correlations among recognition (encoding) and the mediating variable indicators (processing speed $\underline{r}$ = .28, .32; working memory $\underline{r}$ = .18, .13; executive function $\underline{r}$ = .23, .16, .13). Thus, even if encoding was operationalized using the Recognition Discriminability index, it appears as if its relationship to the mediating variables of interest is similar to the relationship of retrieval and the mediating variables of interest.

By examining the correlation matrix in Table 5, one can also see that the number of perseverative errors on the WCST is the only variable related to encoding, even though WCST did not predict encoding in the SEM model. Nevertheless, the relationship is significant and is consistent with previous research suggesting that executive function may be particularly important for memory encoding processes (e.g., Bryan et al., 1999). Also interesting is the fact the memory retrieval was most strongly related to processing speed as compared to working memory and executive function. This is consistent with the suggestion made by Bryan et al. (1999) that while executive function may be particularly important for encoding, processing speed may be more important for memory retrieval.

Modest correlations with age. The surprisingly low correlations between age and many of the study variables, including memory should also be addressed. This finding is surprising in light of a long history of past research consistently demonstrating the age-related decline of memory (e.g. Burke & Light, 1981; Golski et al., 1998; Moscovitch & Winocur, 1995; Paolo et al., 1997; Shimamura, 1990), working memory (Baddeley, 1986, 1990; Charness, 1987; Fisk & Warr, 1996; Light & Anderson, 1985; Salthouse, 1988; Salthouse & Babcock, 1991; Balota et al., 2000 and Zacks et al., 2000 provide recent reviews), processing speed (Fisk & Warr, 1996; Salthouse, 1985; Spreen & Strauss, 1998) and executive function (Boone et al., 1990, 1993; Craik et al., 1990; Diagneault & Braun, 1993; Haaland et al., 1987; Houx et al., 1993; Leach et al., 1991; Mejia et al., 1998; Mittenberg et al., 1989; Nielson et al., 2002; Parkin & Walter, 1992; Shimamura et al., 2001; Toros, 2001; Uttl & Graff, 1997; Whelihan & Lesher, 1985). It may be that this sample population is surprisingly intact and well functioning, and among this group, age may not be a very important variable with respect to memory and other cognitive functioning. In that case, it would be important to compare this group to other less intact groups of older individuals to ascertain what protective factors (e.g., education) may involved in age-related cognitive decline. In addition, however, this could also be an underestimate of the variance in memory and other cognitive abilities attributable to age in which case it is necessary to raise questions related to the measurement of intended constructs and characteristics of the sample, each of which is discussed in the following section.

Methodological Considerations

In assessing the quality of research in this area, it is possible that some difficulties of interpretation arise due to certain methodological limitations. Below is a discussion of the major limitations identified in this area of research in general and in the present investigation more specifically.

The measurement model. The use of different measures, or operational definitions, of the intended constructs across individual studies has created difficulty in interpretation. Operationally defining the constructs of interest in an inconsistent way poses a particularly troublesome limitation in this area of research. What is the most accurate way of assessing constructs such as executive function, processing speed and working memory? The answer to this question has been different depending on the study, making comparison between studies and interpretation of the data very difficult. This question also raises issues of construct validity and highlights the need to use multiple measures when attempting to assess constructs of the sort examined in this study. Using multiple measures in and of itself does not entirely resolve the issue, however, in that the multiple measures might not be very highly correlated with one another, as was the case here. This points to the centrality of construct validity issues in this area.
Nevertheless, the use multiple measures of constructs within any particular study is ideal as it works to minimize the variance specific to particular procedures or from the stimulus materials used to assess these constructs. That is, no single test is likely to be a pure or completely accurate estimate of the intended construct because of the influence of task-specific factors even if the task seems to meet the criteria outlined in the definitions and current understanding of these constructs. More specifically, the variance within any given measure may involve: (1) variance associated with the theoretical construct it purports to measure; (2) variance associated with specific aspects of the measure itself (e.g. stimulus materials, procedure, etc); (3) variance associated with random error

variance or unsystematic error; and (4) variance associated with theoretical constructs one is not trying to measure, but that the test is picking up nonetheless. Thus, there are three out of four sources of variance contributing to the score obtained for an individual on some measure are construct-irrelevant (i.e., they interfere with the accurate assessment of the intended construct). Even though the tests used in this study are very popular and widely accepted, some research has suggested that they have problems with both sensitivity and specificity (Reitan & Wolfson, 1994). The Wisconsin Card Sorting Test (WCST), for example, has been criticized for its lack of specificity as an indicator of frontal lobe functioning (Anderson, Damasio, Jones, & Tranel, 1991) and for the lack of available reliability data (Spreen & Strauss, 1998).

This is coupled with the fact that the sensitivity of executive function measures, including the WCST, to detect mild age-related changes has been recently questioned (Bryan & Luszcz, 2000). While neuroimaging studies of normal older adults do indicate frontal deterioration, the changes are less severe than they are in a clinical population. Thus, finding a way to sensitively measure frontal deterioration in older adults is likely a challenge. In addition, a number of recent review articles have suggested that our traditional measures of executive function may not reflect frontal lobe function (Anderson, Damasio, Jones & Tranel, 1991; Mountain & Snow, 1993, Reitan & Wolfson, 1995). Further, a review of the WCST as a measure of frontal lobe pathology concluded that the majority of evidence does *not* support this use of the test in clinical work or research (Mountain & Snow, 1993). These authors found only six studies comparing normals to patients with frontal lobe damage on the WCST, and of those, only 2 studies reported a significant difference. In addition, there was weak evidence that a difference existed between frontal lobe damaged subjects and subjects with damage in other areas of brain on the test. Finally, the classification rate was not superior to base-rate classification in identifying frontal damage. Thus, the authors stated that declaring the WCST as a test of frontal function was at best premature (Mountain & Snow, 1993). This drastically undermines the evidence suggesting executive function is an important mediator in age-related memory decline.

Imperfect measurement is a limitation that extends beyond the use of the WCST. It is plausible and likely that tasks such as the Stroop Color and Word Test (Stroop) require working memory processing demands to some extent even though this test was not used as a primary measure of this construct in the present study; instead, the backwards form of the WAIS-R Digit Span subtest was used as the measure of working memory. This is but one example of the overlap of functions assessed by each of the tests used in this study and the difficulty in interpretation that can arise when attempting to accurately operationalize these constructs.

In light of this information, the use of multiple measures of any given construct becomes very important. The present study used multiple measures of most study construct, excluding memory performance, and unfortunately included a measurement model that produced a somewhat poor fit to the data. More specifically, the three indicators for executive function and the two indicators of working memory had relatively small factor loadings. The former is actually consistent with recent claims that there is no pure construct of executive function (Bryan & Luszcz, 2000; Miyake et al., 2000; Parkin, 1998, Rabbitt, 1997). These researchers argue that executive functioning processes are not specifically linked to frontal regions of the brain and, in fact, the use of the term 'executive functioning' as a general, catch-all construct for many underlying cognitive abilities is misled and empirically unjustified. Recall that these researchers point to evidence suggesting that the localization of various cognitive abilities collectively known as executive functions falls into many different areas of the brain depending on the specific ability in question. The findings of this study are also consistent with Rabbitt's (1997) factor analysis, which indicated that tasks of executive function did not load on a common factor in a sample of healthy older adults.

The sample. The second major limitation in this study is concerned with its sample which consisted of normal, older adults. Exclusions from the sample were made when subjects indicated clinical levels of depression, exhibited impairment on a dementia screener and/or reported a history of neurological injury/disease. This was to ensure that the final sample would consist only of those individuals experiencing the normal aging process. However, this was a fairly well-functioning (generally healthy, highly educated and Caucasian) sample and may therefore have encompassed selection biases not controlled for in this study. For instance, the mean years of education in this sample was 15.66, which is relatively high. Samples such as this are underrepresentative of socioeconomic, educational and other types of relevant variation in the general population; however, there is clearly interest in understanding how well educated, highly functioning older adults are performing as a group as they age, as this is certainly an understudied population. It is simply important for the reader to note this particular aspect of the sample used in this study and to take it into consideration when attempts are made to generalize the findings in this study to a larger population of older individuals. Nevertheless, as mentioned earlier, this lack of variation in the sample likely contributed to an attenuation of the correlations in this study.

This discussion highlights the fact that a wider range of ages was not included in this study. Including younger participants would have likely increased the range of variation in performance, an important study characteristic when one is attempting to partition out both unique and shared effects as in the common cause analyses (Salthouse, 2001), as well as the age-related declines in the hypothesized mediators. In addition, the inclusion of a younger group would have made it possible to examine other interesting research questions such as: Does executive functioning relate to the types of memory assessed in this study in normal young subjects, or is the age-related impairment in functioning necessary before the relation appears? On the other hand, a younger group could introduce cohort or generation biases into the study. Cross-sectional studies have the potential to lead to an overestimation of age-related cognitive changes due to cohort or generational factors and the obvious solution, longitudinal investigations, have a tendency to underestimate cognitive decline due to selective attrition of subject samples over time (Boone et al., 1990)

Correlational research. It is the view of this author that a third limitation in this research lies in the nature of its design. More specifically, this study is correlational in nature. Therefore, causal inferences cannot be made concerning the decline of memory with age. This point is very important to keep in mind, certainly when making interpretations from the data, but also in outlining the methodological issues surrounding this area of research.

Related to the issue of causality is the fact that it is very difficult, if not impossible, to sort out all of the possible contributing variables surrounding or cooccurring with the decline of memory with age. These other, uncontrolled variables serve to impede any attempt to isolate the contributions of particular variables of interest. Furthermore, correlational data indicates associations between variables of interest, but offers no explanation as to why these relationships exist. It is necessary to estimate significant relationships, but it is also necessary to postulate the mechanisms through which the relationships exist. This kind of analysis can be partially accomplished through the use of structural modeling analyses as in the present study, a clear improvement from the hierarchical regression analyses that dominated this area of research in the recent past. However, simply by using structural equation modeling and assigning arrows going to and from constructs clearly does not provide all the required evidence of an appropriate causal model. Rather, strong theory and longitudinal or experimental designs are often required to unpack complex theoretical relationships, such as the ones studied here.

Future Research

As briefly mentioned above, there are some noteworthy comments to be made concerning the data analysis and measurement of constructs for future research in this area. With respect to data analysis, the importance of using factor analytic techniques in this area of research is worth noting. Future research must strive to achieve pure measure of the constructs of interest. The use of confirmatory factor analytic techniques allows one to verify that the measures used in a particular study reflect the purported underlying constructs. As was seen in the present study, even the most standardized, well-accepted measures of certain constructs did not hang together well in this sample.

In addition, based on the findings of this study that the measures of executive function did not hang together, future research should work to piece apart the different aspects of executive function and then develop multiple measures for each so that we can deal with a more precise specification of the underlying ability and its influence on memory performance.

Future research should concentrate on trying to more accurately operationalize memory process constructs. As Curtiss and colleagues (2001) point out, this can be difficult because memory processes are relational. However, it would be important to be able to accurately identify and measure them because it "would yield information regarding the specific nature of...memory difficulties...[and] would have implications for alternative rehabilitation approaches" (p. 575). Cognitive training intervention with older adults has been found to be successful (Ball et al., 2002). Finding out more about the specific nature of the memory difficulties older adults experience, as well as the mediating influences on these difficulties, will enable us to better design such interventions in such a way that increases their effectiveness. Future research using methods that more directly measure brain activity, such as fMRI or electrophysiological measures, would also clarify the contribution of the prefrontal cortex to age-related memory decline. In addition, future research would likely benefit from studying age-related differences in other types of memory not accounted for in this study (i.e., prospective memory).

Still, other researchers have argued that it is not helpful to think about localization specific to one single part of the brain, as in the case of executive function in the frontal lobes. Instead, they argue we should be thinking in terms of brain circuitry, and focusing our understanding of age-related changes in cognition in association with this perspective (e.g., frontal-striatal circuits, Rubin, 1999; frontal-temporal-parietal circuits, Schumacher, Lauber, Awh, Jonides & Smith, 1996). Thus, given the frontal lobes extensive connections with other areas of the brain, it is very likely that measures of frontal function are affected by damage or deterioration of other brain areas by association. This line of thought has also been discussed as a network-based model of aging and cognition by Greenwood (2000). Recall that a recent review by Greenwood (2000) concluded that researchers are not paying enough attention to the evidence that suggests other areas of the brain change with age as well, and that the localizationist approach is not empirically supported. Indeed, some research has indicated that other brain regions deteriorate at a similar or even faster rate than the prefrontal cortex (e.g., deLeon et al., 1984).

Indeed, the field seems to be going in the direction of identifying neural networks. With respect to declarative memory performance, this would mean examining a frontotemporal network that many researchers are already investigating (Ragland et al., 1997). As opposed to thinking of executive function as a frontal lobe ability and declarative memory as a medial temporal ability, evidence suggests that there is actually a reciprocal network between these two brain structures responsible for successful completion of both cognitive abilities. For example, poorer performance on the WCST has been associated with temporal damage (Corcoran & Upton, 1993) and poorer declarative memory performance has been associated with frontal lobe lesion (Wheeler et al., 1995). Ragland et al., (1997) found an overlap of frontal and temporal activation for a declarative memory task and the WCST, which they took as evidence to support the existence of such a network. In addition, they provided compelling arguments against alternative interpretations of the data (e.g., the possibility that the two tests simply tapped the same cognitive function).

Finally, and most importantly, continued research into the nature of the common causal mechanism is warranted. The results of this study and the results of other recent investigations (e.g., Salthouse & Czaja, 2000) suggest that age primarily exerts its influences on a broad, higher-order factor that, in turn, causes decline in many areas of cognitive ability, including memory. This is important because it calls for more generalistic explanations of the cognitive aging process as opposed to the more specific mediational hypotheses originally proposed in this study. Stated more explicitly, it appears that the independent effects age has on particular cognitive variables is relatively small in comparison to the more general effects that seem to be occurring, represented by the variance that is shared among the individual cognitive variables.

Summary and Conclusions

The present study found tentative support for the hypothesis that free-recall memory performance depends on the mediating resources of interest to a greater extent than does recognition memory performance. With respect to the mediating constructs themselves and the relationships among them as they relate to age-related memory decline, it appears that processing speed mediates the relationship between age and working memory performance. In an attempt to compare the mediating influences of processing speed, working memory and executive function on both memory encoding and memory retrieval, it was found that none of the links between the mediators to the dependent variables were significant, suggesting that the variance may be shared. Thus, a common cause model of aging was tested that seemed to fit better for memory retrieval. Another notable aspect of the present study was that the measurement model was far from ideal. Therefore, it is advised that future research focus on the measurement of important cognitive aging constructs. This is in agreement with Van der Linden et al. (1999) who stated, "An agreement within the scientific community on the proper measurement of speed, inhibition, and working memory is more important [than comparing various structure models], and such a measurement can only be validated by a thorough analysis of the underlying mechanisms" (p. 50). In addition, the idea that cognition is produced by complex neural network associations as compared to single localization of function also warrants further investigation. This will help us to further elucidate the mechanisms through which age-related memory decline occurs.

APPENDIX

Table 1. List of study hypotheses

Number	Hypothesis
1	Free-recall memory will rely on the mediating resources (processing speed, working memory and executive function) to a greater extent than will recognition memory.
2a	Processing speed will mediate the relationship between age and verbal memory encoding after accounting for its indirect effects via executive function and working memory.
2b	Processing speed will mediate the relationship between age and verbal memory retrieval after accounting for its indirect effects via executive function and working memory.
3	Processing speed will mediate the relationship between age and working memory.
4a	Working memory will mediate the relationship between processing speed and verbal memory encoding.
4b	Working memory will mediate the relationship between processing speed and verbal memory retrieval.
5a	Executive function will mediate the relationship between age and verbal memory encoding.
5b	Executive function will mediate the relationship between age and verbal memory retrieval.
6a	Executive function will mediate the relationship between processing speed and verbal memory encoding.
6b	Executive function will mediate the relationship between processing speed and verbal memory retrieval.
7a	Working memory will mediate the relationship between executive function and verbal memory encoding.
7b	Working memory will mediate the relationship between executive function and verbal memory retrieval.
8	Executive function will be more strongly related to memory as age increases.
9	A higher MMSE score will be associated with a stronger relationship between processing speed and memory. That is, processing speed should be more strongly related to memory function among intact individuals.
10	A lower MMSE score will be associated with a stronger relationship between executive function and memory. That is, executive function should be more strongly related to memory function among non-intact individuals.

Table 2. Primary study constructs and measurements

Construct	Measure(s)
Processing Speed	Symbol Digit Modalities Test (SDMT; Smith, 1991) written and oral total scores
Working Memory	WMS-R Backward Digit Span (DSpB; Wechsler, 1987) total score
	WMS-R Backward Visual Memory Span (VMSpB; Wechsler, 1987) total score
Executive Function	Stroop Color and Word Test (Stroop; Golden, 1978) interference score
	Wisconsin Card Sorting Test (WCST; Heaton, 1981) number of perseverative errors
	Trailmaking Test (TMT; Reitan, 1958) Part B – Part A
Verbal Memory	California Verbal Learning Test (CVLT; Delis et al., 1987)
Recall	Average of Trials 1-5, Long-delay and Short delay free-recall trials (CVLT-FR)
Recognition	Recognition Discriminability index (CVLT-RD)
Encoding	Semantic Cluster Ratio (CVLT-SCR)
Retrieval	Discrepancy between Recognition and Recall Discriminability Indexes (CVLT-RD/FR)

Table 3. Means, standard deviations, and pairwise intercorrelations among the indicators of working memory (WM), processing speed (PS), executive function (EF), memory encoding, retrieval, recall, recognition and age *before* estimation and imputation of data

Constructs (Measures)	Mean	SD	N	1	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Age	70.01	8.1	305	1.00											
2. WM (DSpB)	6.45	2.2	308	-.20**	1.00										
3. WM (VSpB)	7.23	1.6	303	-.22**	.29**	1.00									
4. PS (DSMT written)	44.20	10.7	297	-.55**	.35**	.33**	1.00								
5. PS (DSMT oral)	51.49	13.2	292	-.52**	.36**	.33**	.87**	1.00							
6. EF[1] (TMT)	-64.23	47.3	303	-.37**	.26**	.27**	.43**	.43**	1.00						
7. EF[1] (ST)	-4.41	7.0	288	-.26**	.18**	.14*	.26**	.22**	.20**	1.00					
8. EF[1] (WCST)	-17.10	13.0	284	-.30**	.16**	.13*	.28**	.27**	.33**	.13*	1.00				
9. Encoding	1.90	1.4	297	-.04	.11	.06	.04	.04	.06	-.01	-.03	1.00			
10. Retrieval	-86.21	39.4	262	-.18**	.12	.12	.28**	.35**	.14*	.10	.18**	.43**	1.00		
11. Free-recall	8.63	2.9	297	-.27**	.18**	.11	.34**	.40**	.22**	.14*	.21**	.31**	.91**	1.00	
12. Recognition	88.83	10.4	297	-.21**	.17**	.02	.24**	.28**	.21**	.12*	.14*	.20**	.31**	.57**	1.00

Notes. * p value <.05, ** p value < .01.
[1]All Executive Function variables were recoded so that negative correlations indicate a decline in performance on these tests with increasing age.
For DSpB = Digit Span Backwards; VSpB = Visual Span Backwards; DSMT = Digit Symbol Modalities Test; Trails = Trailmaking Test; ST = Stroop Color and Word Test; WCST = Wisconsin Card Sorting Test; Encoding = California Verbal Learning Test semantic cluster score; Retrieval = CVLT Free-Recall-Recognition Discrepancy; Free-recall = CVLT average of Trials 1-5, short delay and long delay free recall trails; Recognition = CVLT Recognition Discriminability Index

Table 4. Means and standard deviations of subjects' age, education, estimated VIQ and scores on the MMSE, GDS and BDI

Participant Variable	N	Mean	Standard Deviation
Age (years)	304	70.01	8.1
Years of Education (years)	304	15.66	3.0
Estimated VIQ*	304	118.09	8.6
MMSE total score	304	28.24	1.5
GDS total score	304	5.78	4.8
BDI total score	286	6.63	4.8

Note. The equation used to compute the estimated VIQ = 118.2 - .89 (number of errors on the American version of the New Adult Reading Test) + .64 (Years of Education); (Grober & Sliwinski, 1991).

Table 5. Means, standard deviations, and pairwise intercorrelations among the indicators of working memory (WM), processing speed (PS), executive function (EF), memory encoding, retrieval, recall, recognition and age *after* estimation and imputation of data

Constructs (Measures)	Mean	SD	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Age	70.01	8.1	1.00											
2. WM (DSpB)	6.45	2.2	-.20**	1.00										
3. WM (VSpB)	7.21	1.6	-.23**	.28**	1.00									
4. PS (DSMT written)	44.03	10.9	-.56**	.36**	.36**	1.00								
5. PS (DSMT oral)	51.29	13.3	-.54**	.36**	.34**	.88**	1.00							
6. EF[1] (TMT)	-64.23	47.3	-.36**	.26**	.30**	.46**	.44**	1.00						
7. EF[1] (ST)	-4.53	7.1	-.30**	.21**	.19**	.28**	.24**	.22**	1.00					
8. EF[1] (WCST)	-17.55	13.2	-.31**	.16**	.20**	.29**	.29**	.31**	.13*	1.00				
9. Encoding	1.82	0.8	-.11	.11	.06	.09	.10	.07	.07	.12*	1.00			
10. Retrieval	-86.75	39.8	-.24**	.13*	.11*	.26**	.33**	.20**	.16**	.19**	.50**	1.00		
11. Free-recall	8.57	2.9	-.29**	.18**	.13**	.33**	.39**	.25**	.19**	.22**	.57**	.93**	1.00	
12. Recognition	88.86	9.4	-.22**	.18**	.07	.28**	.32**	.23**	.16**	.13*	.34**	.47**	.65**	1.00

Notes. * p value <.05, ** p value < .01.

[1]All Executive Function variables were recoded so that negative correlations indicate a decline in performance on these tests with increasing age.

For DSpB = Digit Span Backwards; VSpB = Visual Span Backwards; DSMT = Digit Symbol Modalities Test; Trails = Trailmaking Test; ST = Stroop Color and Word Test; WCST = Wisconsin Card Sorting Test; Encoding = California Verbal Learning Test semantic cluster score; Retrieval = CVLT Free-Recall-Recognition Discrepancy; Free-recall = CVLT average of Trials 1-5, short delay and long delay free recall trails; Recognition = CVLT Recognition Discriminability Index

N = 304

Table 6. Completely standardized expected change and modification indices for factor loadings of indicator variables on latent constructs

Indicator	PS	WM	EXEC
DSMWRTN		.06 (0.35)	.08 (0.32)
DSMORL		-.02 (0.04)	-.08 (0.32)
DBACKTOT	.22 (1.02)		.02 (0.00)
VSMEMBAC	-.22 (1.02)		-.02 (0.00)
R_INTERF	-.01 (0.01)	.21 (1.02)	
R_TRAIL	.13 (0.48)	.25 (0.83)	
R_PERERR	-.09 (0.43)	-.06 (0.09)	

Note. First number in each row is completely standardized expected change. Numbers in parentheses are modification indices.

Table 7. Listing of key hypotheses relating to conceptual model for memory *encoding*, linkages and completely standardized path coefficients

Hypothesis	Link(s)	Completely Standardized Path Coefficients	Hypothesis Supported?	Total Effect (product of two path coefficients)
H2a: Processing speed will mediate the relationship between age and verbal memory encoding after accounting for its indirect effects via executive function and working memory.	a e	-.58* -.07	No	--
H3: Processing speed will mediate the relationship between age and working memory.	a d	-.58* .29*	Yes	-.17*
H4a: Working memory will mediate the relationship between processing speed And verbal memory encoding.	d g	.29* .11	No	--
H5a: Executive function will mediate the relationship between age and verbal memory encoding.	b h	-.25* .12	No	--
H6a: Executive function will mediate the relationship between processing speed and verbal memory encoding.	c h	.58* .12	No	--
H7a: Working memory will mediate the relationship between executive function and verbal memory encoding.	f g	.56* .11	No	--

Note. * $p < .05$

Table 8. Fit indices to test Mediational Model for memory encoding (N = 304)

Test for Processing Speed

Model specification	Figure	Model Comparison	χ^2	df	$\Delta\chi^2$	Δdf	p($\Delta\chi^2$)	GFI	AGFI	NNFI	CFI	SRMR	RMSEA
1. Complete	10	--	22.74	20	--	--	--	.98	.96	.99	1.00	.03	.02
2. Mediation Only (Hypothesized Model)	9	1 vs. 2	17.96	21	4.78	1	< .05	.99	.97	1.00	1.00	.03	.00
3. No Mediation	11	1 vs. 3	140.28	21	117.54	1	< .05	.92	.83	.76	.86	.14	.12

Test for Executive Function

Model specification	Figure	Model comparison	χ^2	df	$\Delta\chi^2$	Δdf	P($\Delta\chi^2$)	GFI	AGFI	NNFI	CFI	SRMR	RMSEA
1. Complete	10	--	22.74	20	--	--	--	.98	.96	.99	1.00	.03	.02
2. Mediation Only (Hypothesized Model)	9	1 vs. 2	17.96	21	4.78	1	< .05	.99	.97	1.00	1.00	.03	.00
3. No Mediation	12	1 vs. 3	31.75	21	9.01	1	< .05	.98	.95	.98	.99	.04	.04

Note. GFI = goodness-of-fit index; AGFI = adjusted goodness-of-fit index; NNFI = nonnormed fit index; CFI = comparative fit index; SRMR = standardized root mean-square residual; RMSEA = root-mean-square error of approximation.

Table 9. Listing of key hypotheses relating to conceptual model for memory *retrieval*, linkages and completely standardized path coefficients

Hypothesis	Link(s)	Completely Standardized Path Coefficients	Hypothesis Supported?	Total Effect (product of two path coefficients)
H2b: Processing speed will mediate the relationship between age and verbal memory retrieval after accounting for its indirect effects via executive function and working memory.	i m	-.59* .16	No	--
H3: Processing speed will mediate the relationship between age and working memory.	i l	-.59* .30*	Yes	-.18*
H4b: Working memory will mediate the relationship between processing speed and verbal memory retrieval.	l o	.30* -.19	No	--
H5b: Executive function will mediate the relationship between age and verbal memory retrieval.	j p	-.25* .39	No	--
H6b: Executive function will mediate the relationship between processing speed and verbal memory retrieval.	k p	.58* .39	No	--
H7b: Working memory will mediate the relationship between executive function and verbal memory retrieval.	n o	.56* -.19	No	--

Note. * $p < .05$

Table 10. Fit indices to test Mediational Model for memory retrieval (N = 304)

Test for Processing Speed

Model specification	Figure	Model comparison	χ^2	df	$\Delta\chi^2$	Δdf	$p(\Delta\chi^2)$	GFI	AGFI	NNFI	CFI	SRMR	RMSEA
1. Complete	14	--	26.00	20	--	--	--	.98	.96	.99	.99	.03	.03
2. Mediation Only (Hypothesized Model)	13	1 vs. 2	26.05	21	0.05	1	> .05	.98	.96	.99	.99	.03	.03
3. No Mediation	15	1 vs. 3	143.19	21	117.19	1	< .05	.92	.83	.76	.86	.14	.12

Test for Executive Function

Model specification	Figure	Model comparison	χ^2	df	$\Delta\chi^2$	Δdf	$P(\Delta\chi^2)$	GFI	AGFI	NNFI	CFI	SRMR	RMSEA
1. Complete	14	--	26.00	20	--	--	--	.98	.96	.99	.99	.03	.03
2. Mediation Only (Hypothesized Model)	13	1 vs. 2	26.05	21	.05	1	> .05	.98	.96	.99	.99	.03	.03
3. No Mediation	16	1 vs. 3	35.12	21	9.12	1	< .05	.98	.95	.97	.98	.03	.05

Note. GFI = goodness-of-fit index; AGFI = adjusted goodness-of-fit index; NNFI = nonnormed fit index; CFI = comparative fit index; SRMR = standardized root mean-square residual; RMSEA = root-mean-square error of approximation.

Table 11. Correlations between the four measures of free-recall and recognition memory scores as measured by the CVLT

Score	First Five Trials	Short-Delay Free-Recall	Long-Delay Free-Recall	Recognition Hits
First Five Trials	1.00			
Short-Delay Free-Recall	.82**	1.00		
Long-Delay Free-Recall	.83**	.88**	1.00	
Recognition Hits	.45**	.46**	.47**	1.00

Note. ** $p < .01$.

Table 12. Regression analyses testing linearity of the relationship between executive function and memory (N = 304)

Step and Predictors	Statistics for Step					Statistics for Predictors	
	R^2	df	ΔR^2	Δdf	ΔF	$\hat{\beta}$	t
Step 1	.093	1	--	--	30.929		
Executive Function						.30*	5.561
Step 2	.095	1	.002	0	.660		
Executive Function²						.05	.812

Note. * $p < .05$. Dependent variables is Memory as measured by free-recall and recognition scores on the CVLT.

Table 13. Moderated regressions for age X executive function as a predictor of memory (N = 304)

Step and Mediators	Statistics for Step					Statistics for Mediators	
	R^2	df	ΔR^2	Δdf	ΔF	$\hat{\beta}$	t
Step 1	.117	2	--	--	19.916		
Age						-.18*	-2.858
Executive Function						.22*	3.631
Step 2	.118	1	.001	1	.281		
Age X Executive Function						-.25	.53

Note. * $p < .05$. Dependent variables is Memory as measured by free-recall and recognition scores on the CVLT.

Table 14. Regression analyses testing linearity of the relationship between processing speed and memory (N = 304)

Step and Predictors	Statistics for Step					Statistics for Predictors	
	R^2	df	ΔR^2	Δdf	ΔF	$\hat{\beta}$	T
Step 1	.123	1	--	--	42.167		
Processing Speed						.35*	6.494
Step2	.123	1	.001	0	.245		
Processing Speed²						.027	.495

Note. * $p < .05$. Dependent variables is Memory as measured by free-recall and recognition scores on the CVLT.

Table 15. Moderated regressions for MMSE scores x processing speed as a predictor of memory (N = 321).

Step and Mediators	Statistics for Step						Statistics for Mediators	
	Constant	R^2	df	ΔR^2	Δdf	ΔF	$\hat{\beta}$	T
Step 1	-8.908	.245	2	--	--	51.566		
MMSE scores							.21*	3.810
Processing Speed							.35*	6.281
Step2	-8.888	.245	1	.000	1	.000		
MMSE X Processing Speed							-.01	-.011

Note. * $p < .05$. Dependent variables is Memory as measured by free-recall and recognition scores on the CVLT.

Table 16. Moderated regressions for MMSE scores x executive function predicting memory (N = 321).

Step and Mediators	Statistics for Step						Statistics for Mediators	
	Constant	R^2	df	ΔR^2	Δdf	ΔF	$\hat{\beta}$	t
Step 1	-12.424	.195	2	--	--	38.574		
MMSE scores							.30*	5.443
Executive Function							.23*	4.171
Step2	-11.320	.197	1	.001	1	.568		
MMSE X Executive Function							-.42	-.754

Note. * $p < .05$. Dependent variables is Memory as measured by free-recall and recognition scores on the CVLT.

Table 17. Fit indices to compare Common Cause Model to Mediation Model

Model specification	Figure	χ^2	df	$\Delta\chi^2$	Δdf	P ($\Delta\chi^2$)	GFI	AGFI	NNFI	CFI	SRMR	RMSEA
Mediation Model	13	26.05	21	--	--	--	.98	.96	.99	.99	.03	.03
Common Cause	20	40.50	28	14.45	7	< .05	.97	.96	.99	.98	.05	.03

Notes. GFI = goodness-of-fit index; AGFI = adjusted goodness-of-fit index; NNFI = nonnormed fit index; CFI = comparative fit index; SRMR = standardized root mean-square residual; RMSEA = root-mean-square error of approximation.
Dependent variable is memory retrieval.

Table 18. Fit indices to compare Common Cause Model to a model in which age predicts all outcome variables

Model specification	Figure	χ^2	$\Delta\chi^2$	p ($\Delta\chi^2$)	df	GFI	AGFI	NNFI	CFI	SRMR	RMSEA
Age	21	144.31*	--	--	28	.89	.82	.86	.82	.13	.13
Common Cause	20	40.50	--	--	28	.97	.96	.99	.98	.05	.03

Notes. GFI = goodness-of-fit index; AGFI = adjusted goodness-of-fit index; NNFI = nonnormed fit index; CFI = comparative fit index; SRMR = standardized root mean-square residual; RMSEA = root-mean-square error of approximation.
Dependent variable is memory retrieval.

Figure 1. Proposed mediational model of age-related decline in verbal memory

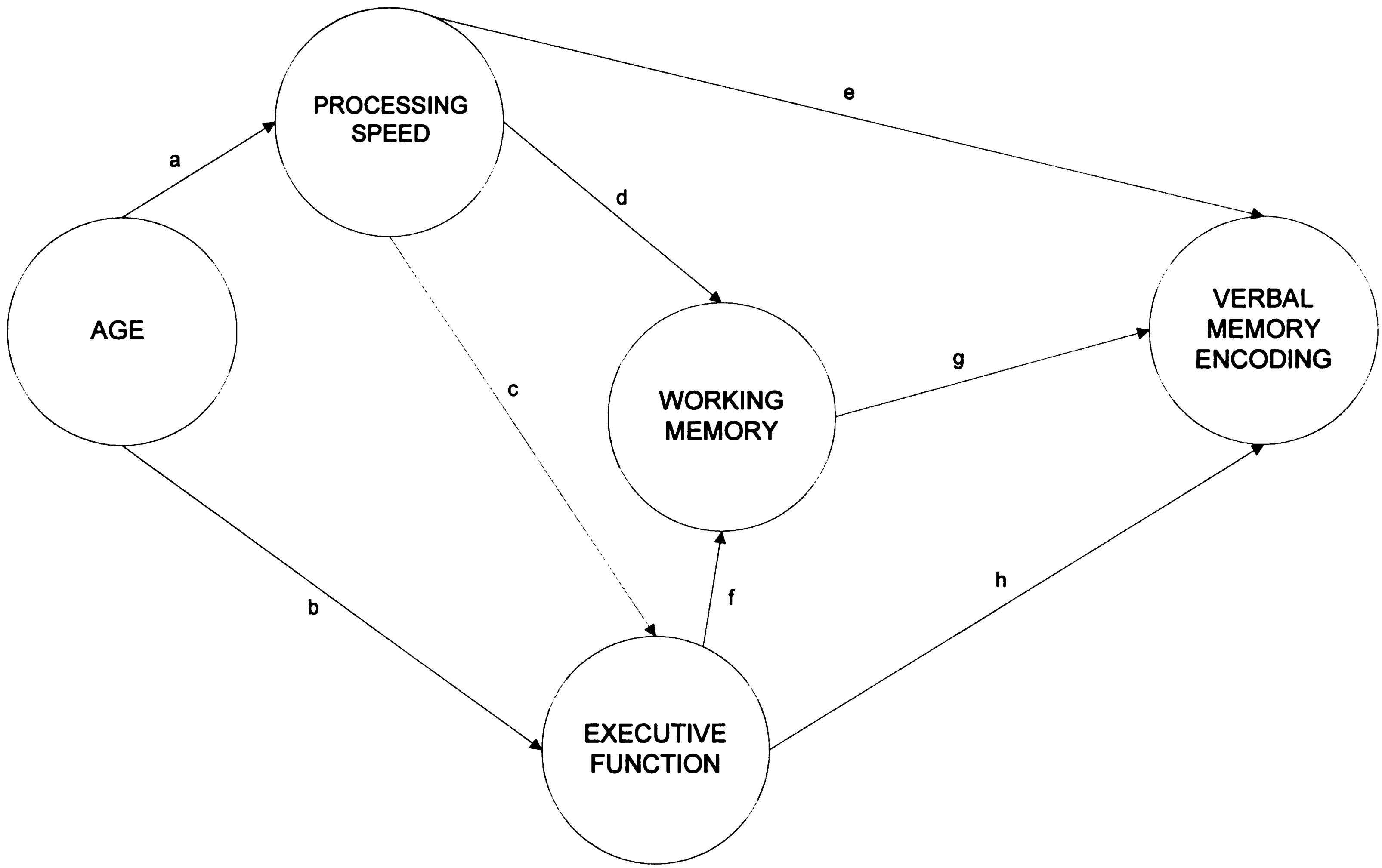


Figure 2. Proposed mediational model of age-related decline in verbal memory retrieval

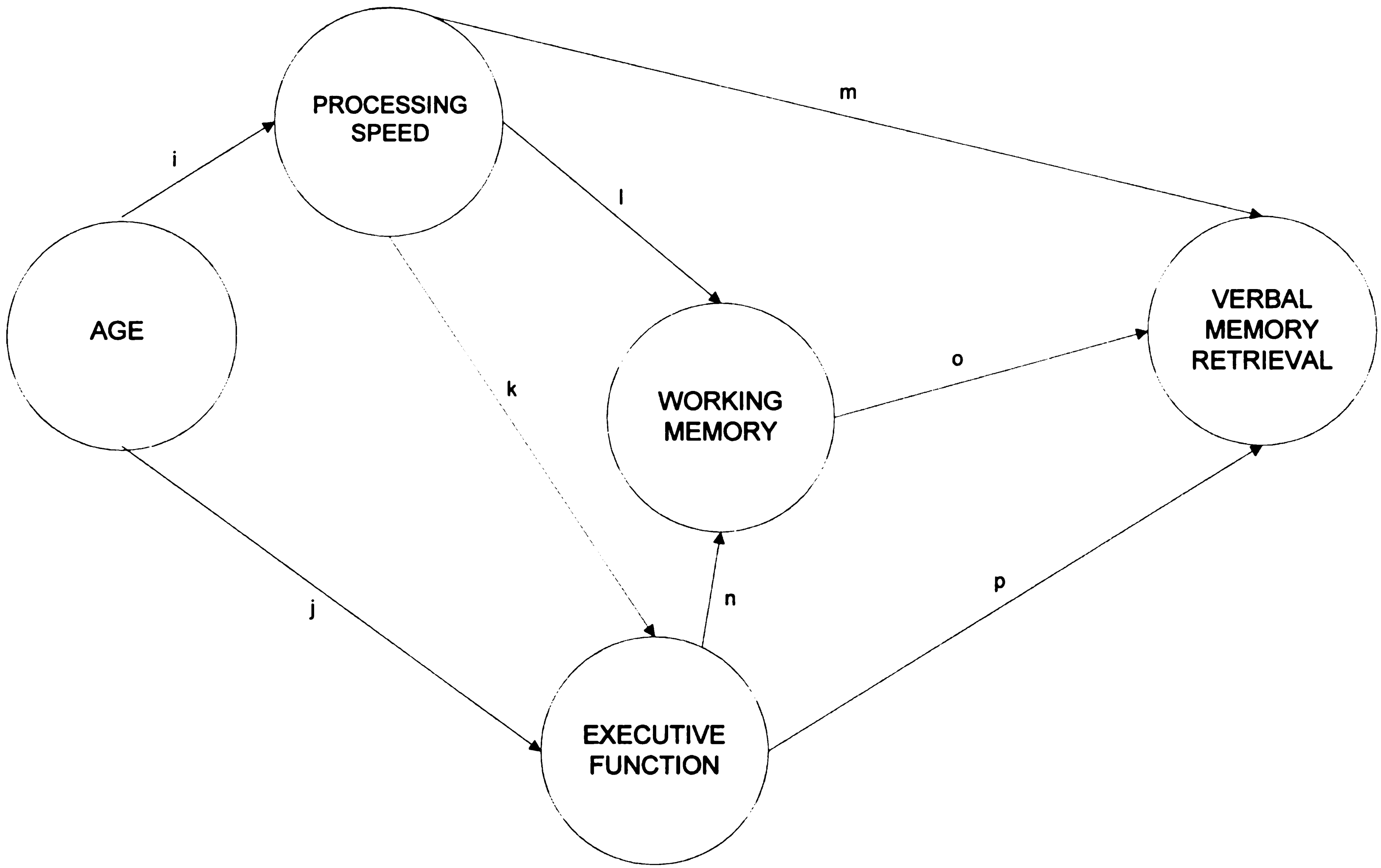


Figure 3. Proposed mediational model of age-related decline in verbal recall memory

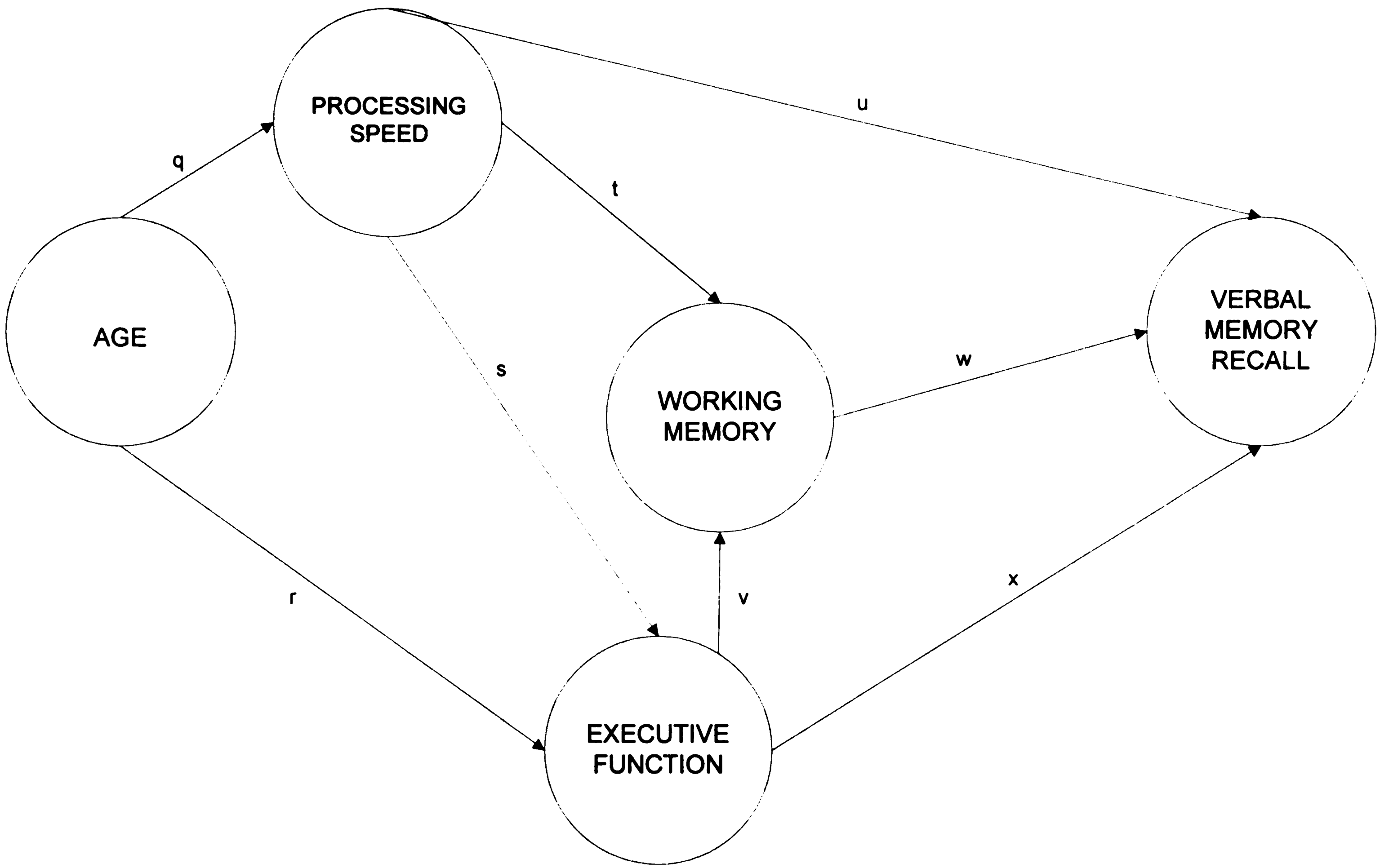


Figure 4. Proposed mediational model of age-related decline in verbal recognition memory

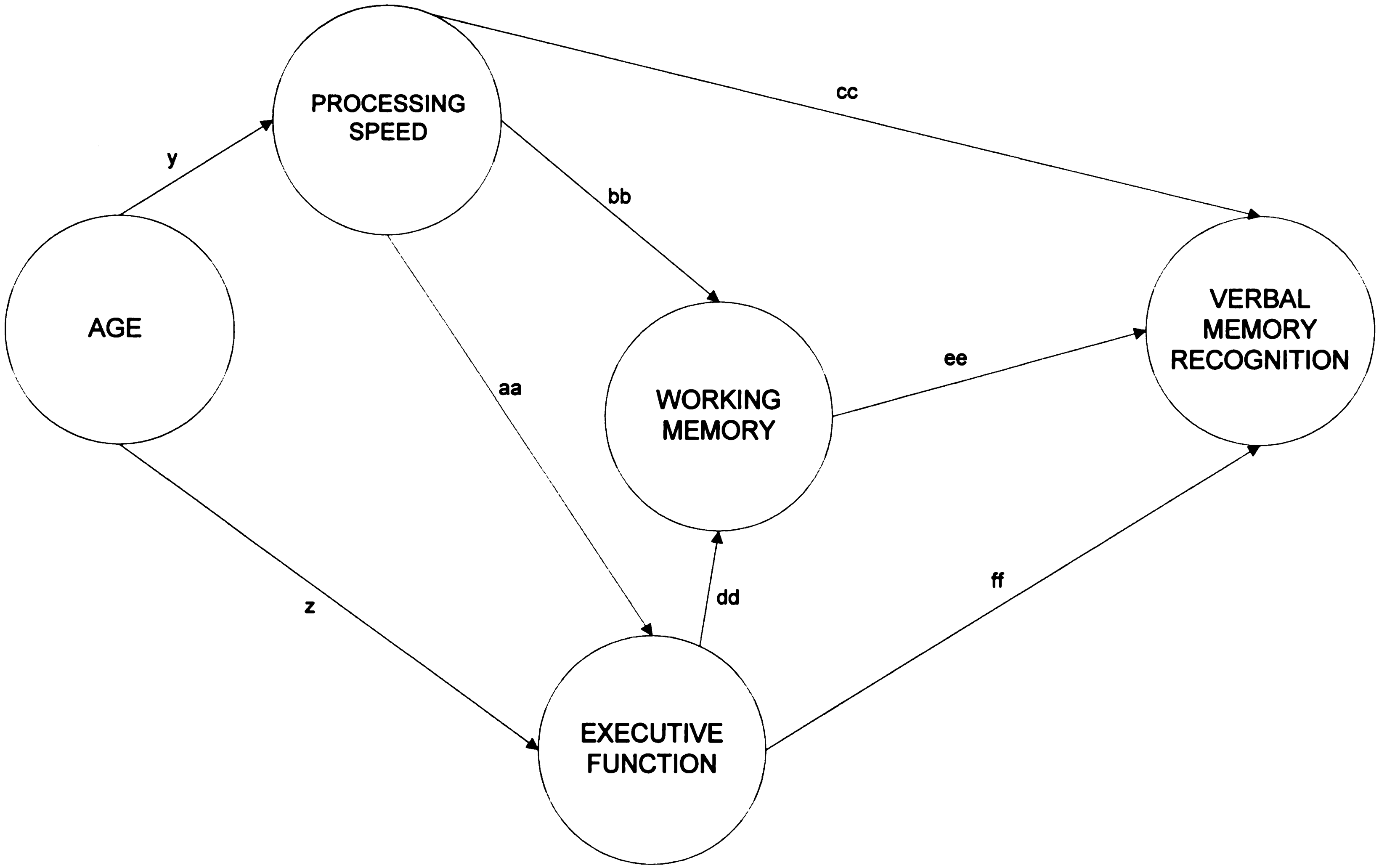


Figure 5. Age as a moderator of the relationship between executive function and memory

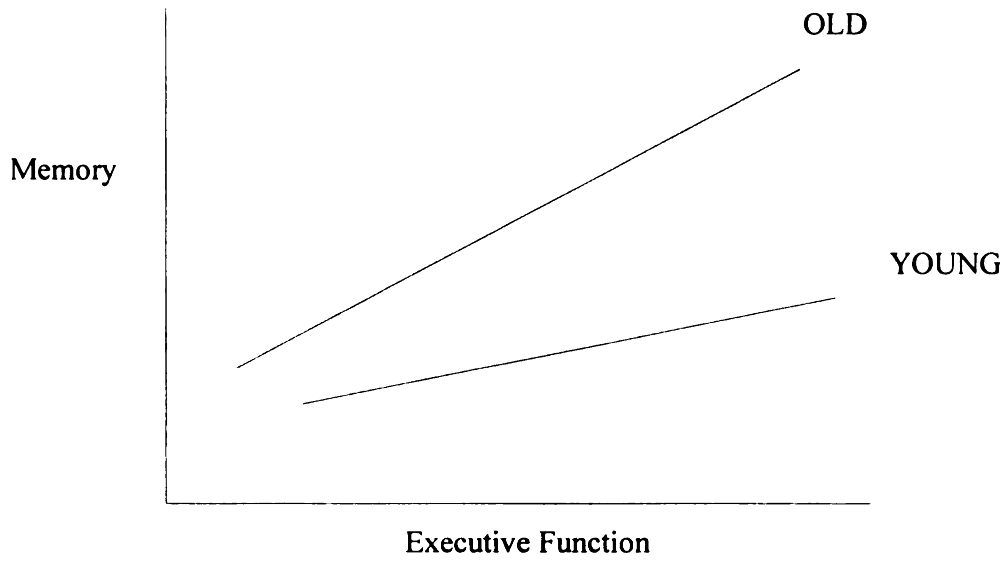


Figure 6. MMSE scores as a moderator of the relationship that both processing speed and executive function have with memory

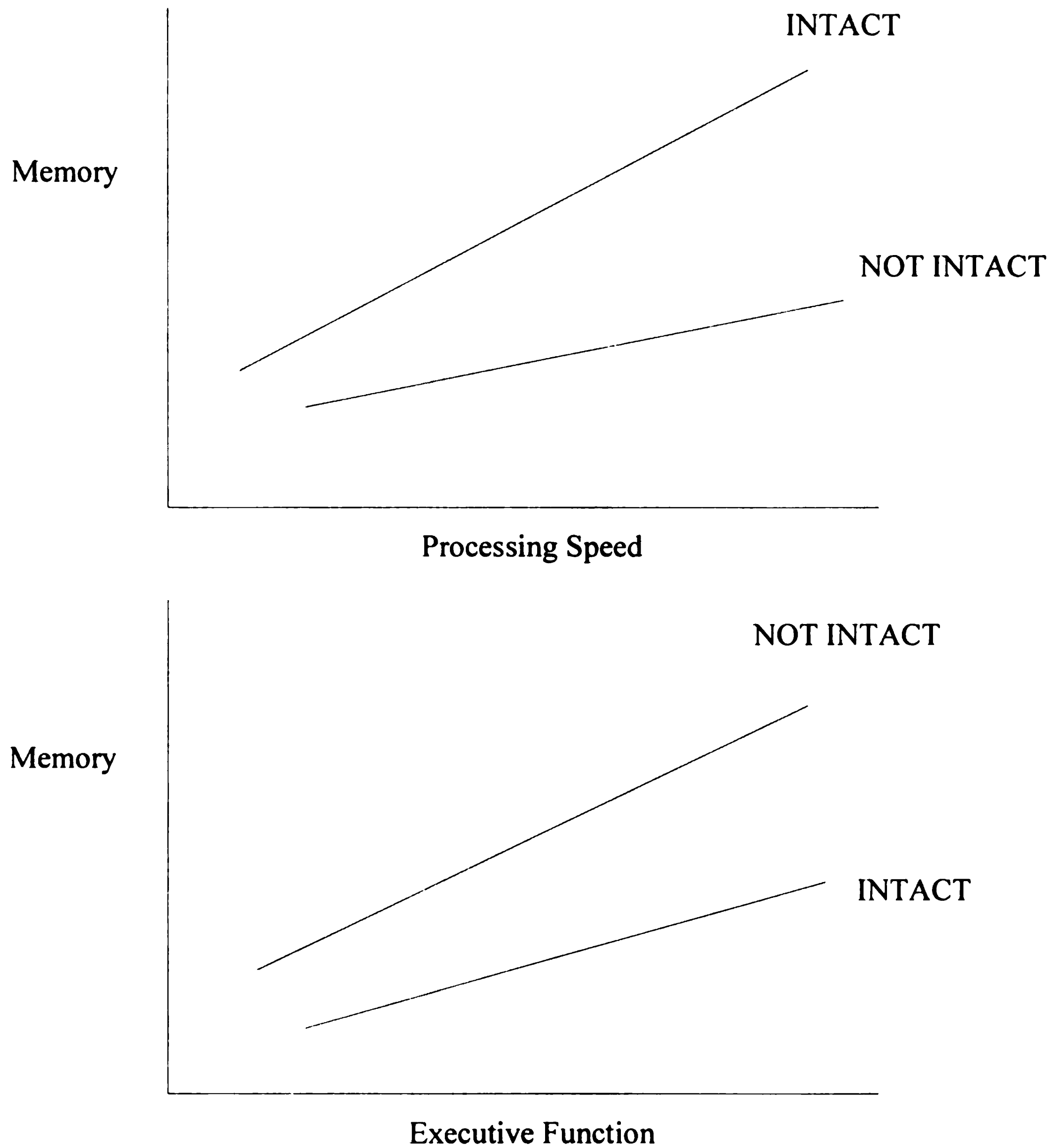
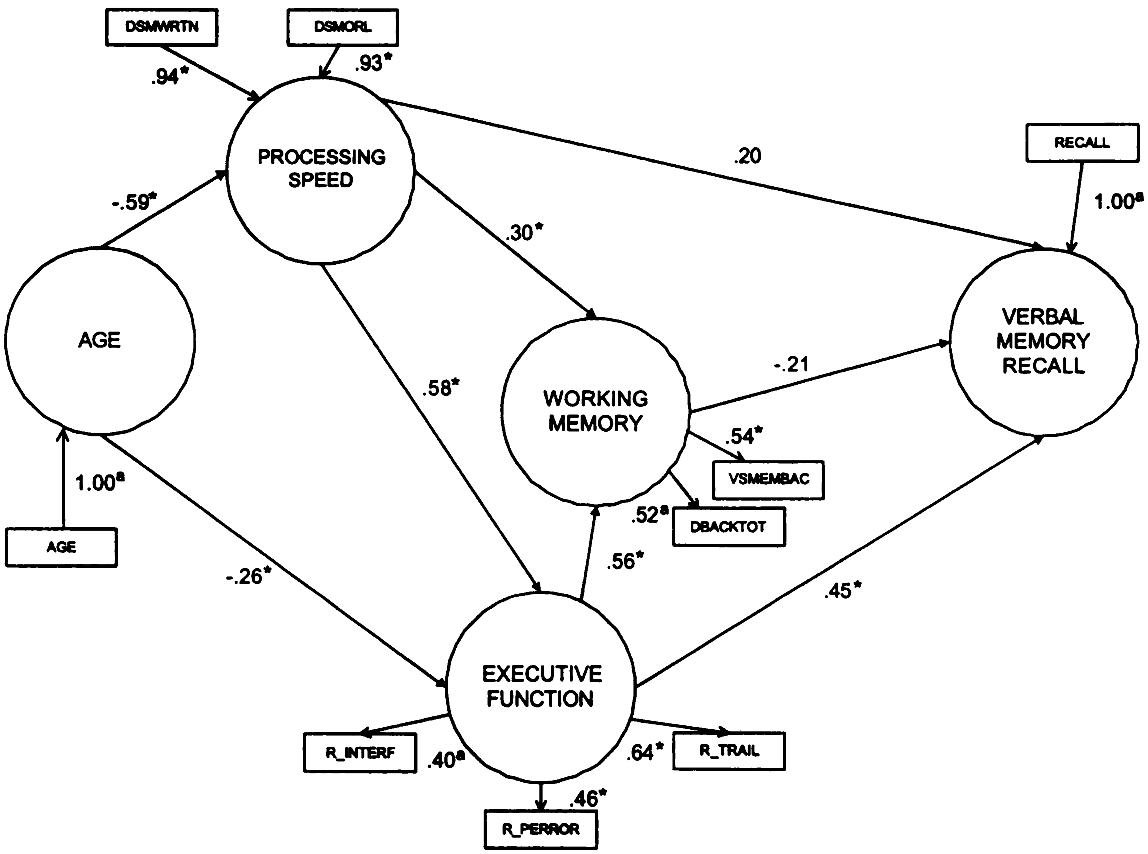
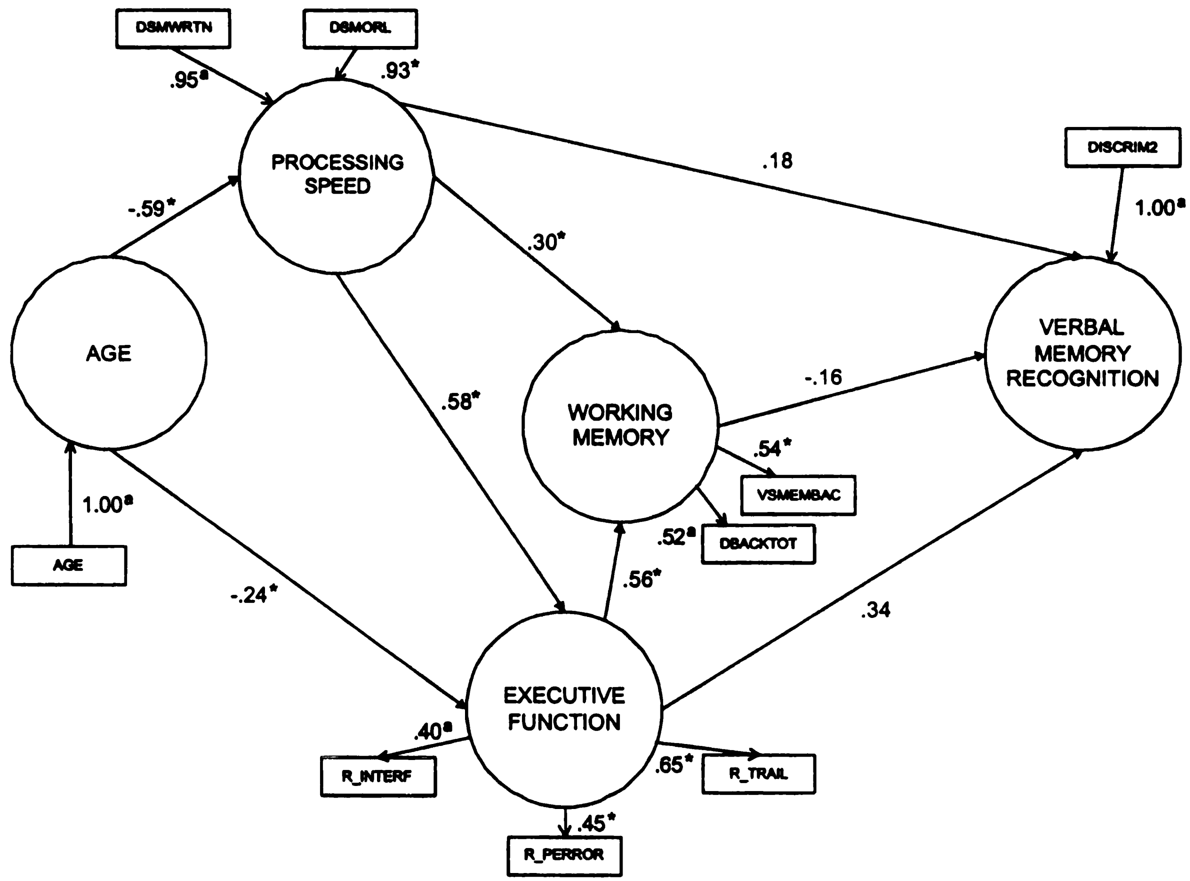


Figure 7. Completely standardized LISREL path coefficients and factor loadings associated with model of age-related decline in verbal recall memory, N = 304



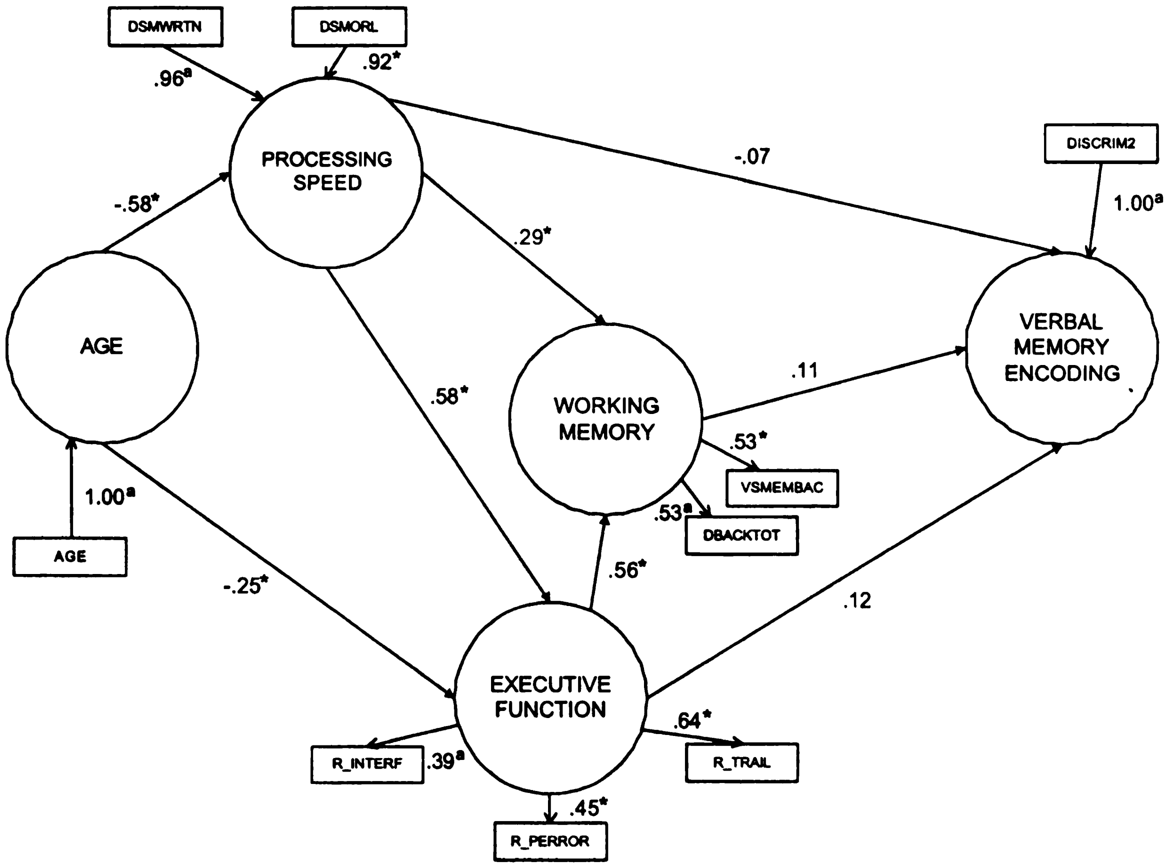
Notes. [a] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. * $p < .05$.

Figure 8. Completely standardized LISREL path coefficients and factor loadings associated with model of age-related decline in verbal recognition memory, N = 304



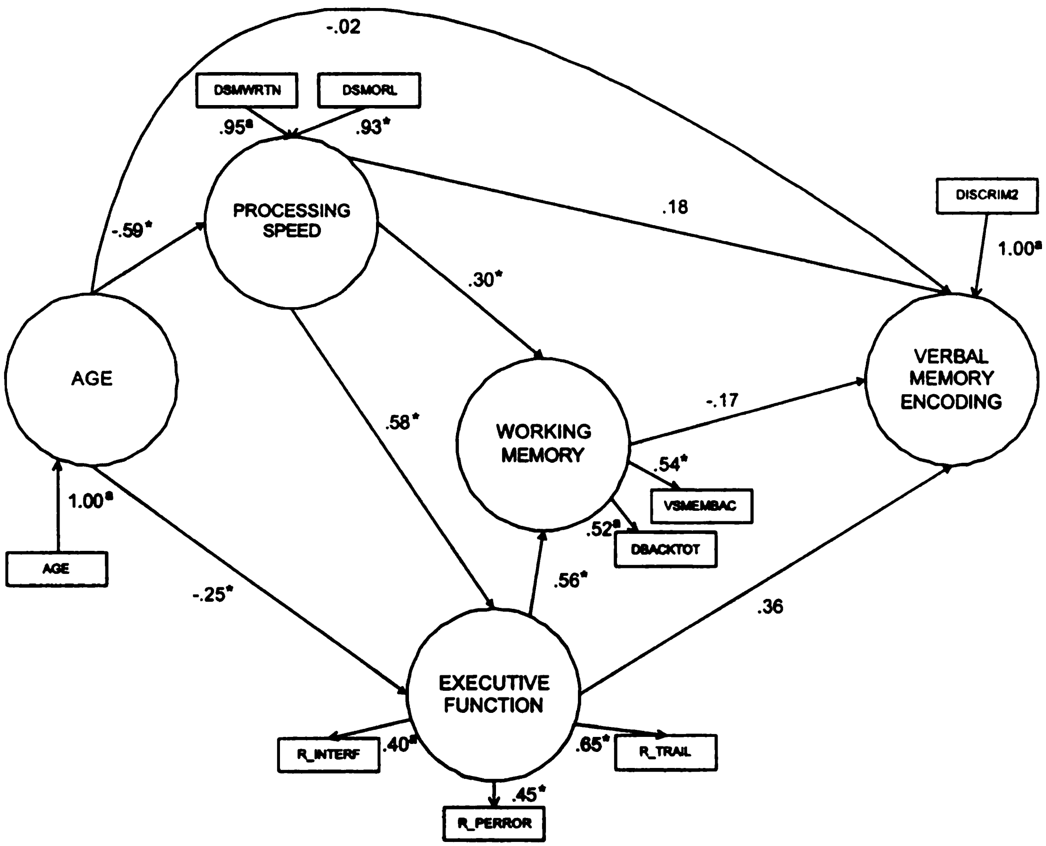
Notes. [a] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. * $p < .05$

Figure 9. Completely standardized LISREL path coefficients and factor loadings associated with model of age-related decline in verbal memory encoding, N = 304



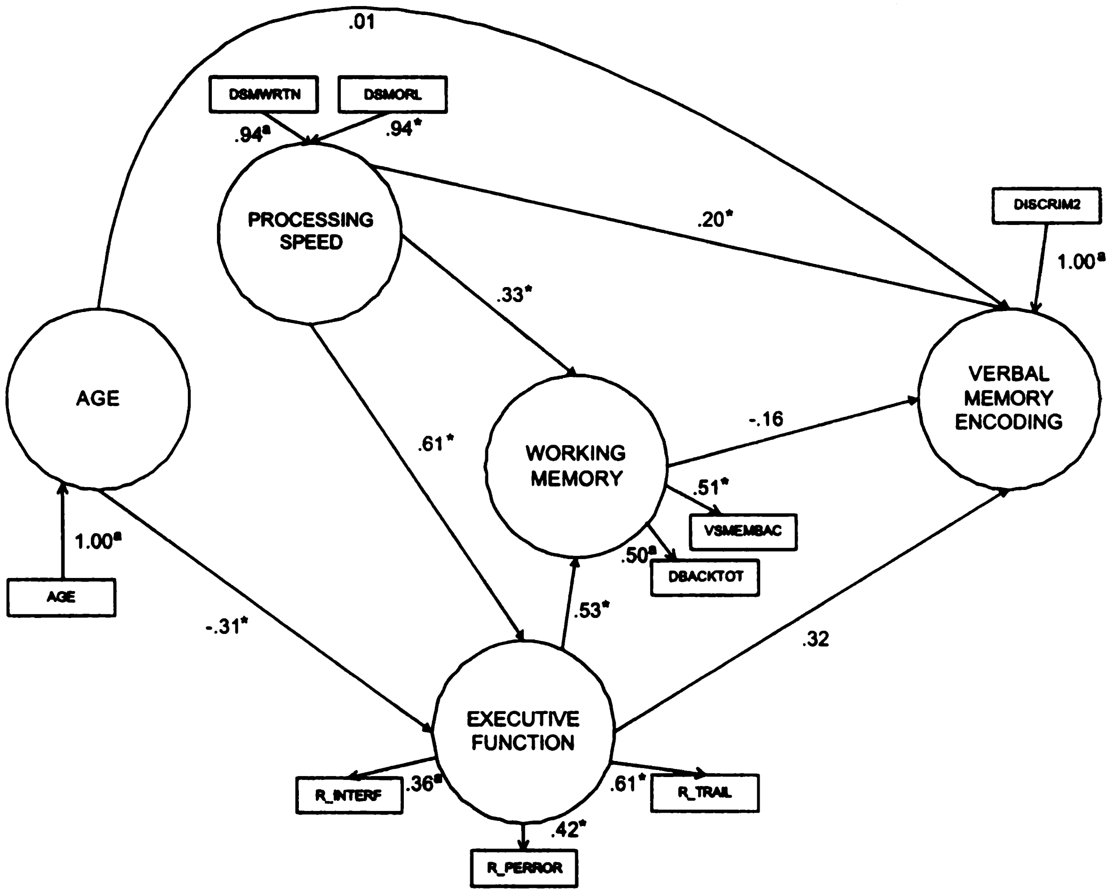
Notes. [a] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. * $p < .05$

Figure 10. Completely standardized LISREL path coefficients and factor loadings associated with the complete path model of age-related decline in verbal memory encoding, N = 304



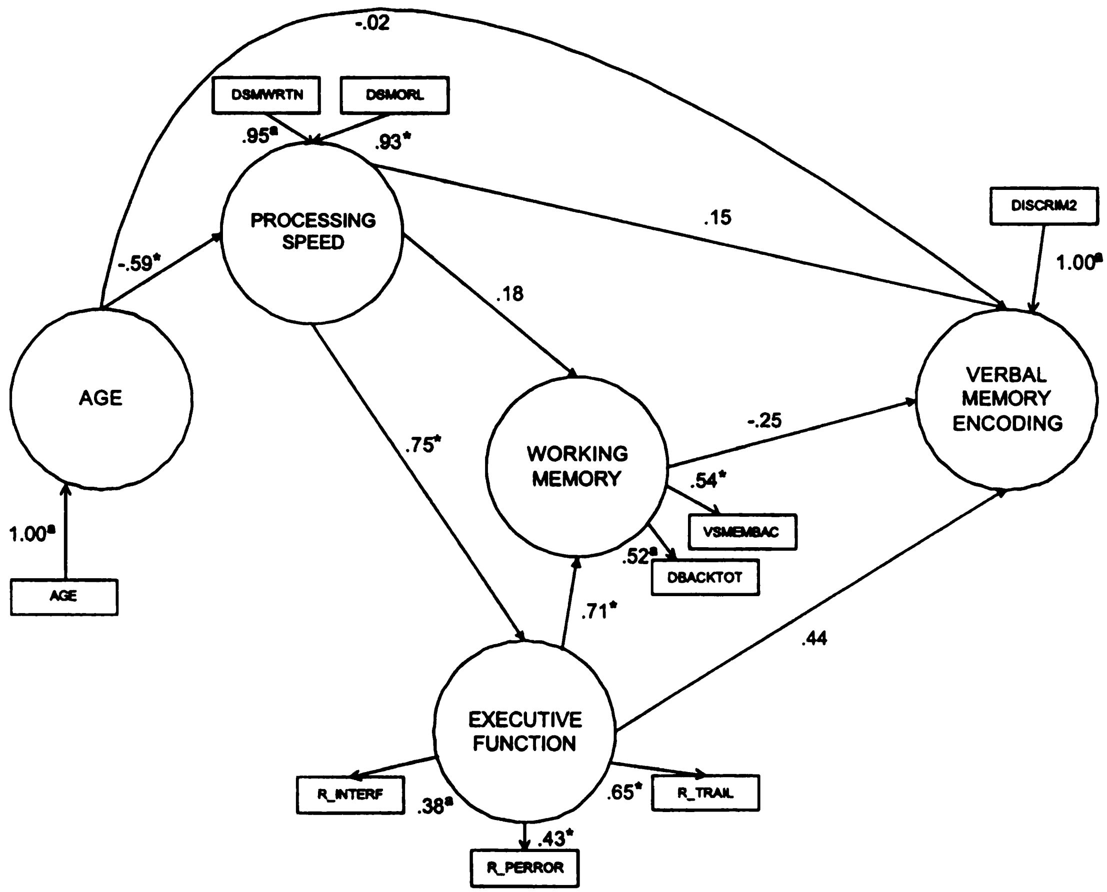
Notes. [a] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. * $p < .05$

Figure 11. Completely standardized LISREL path coefficients and factor loadings associated with the model of no mediation of processing speed in the age-related decline in verbal memory encoding, N = 304



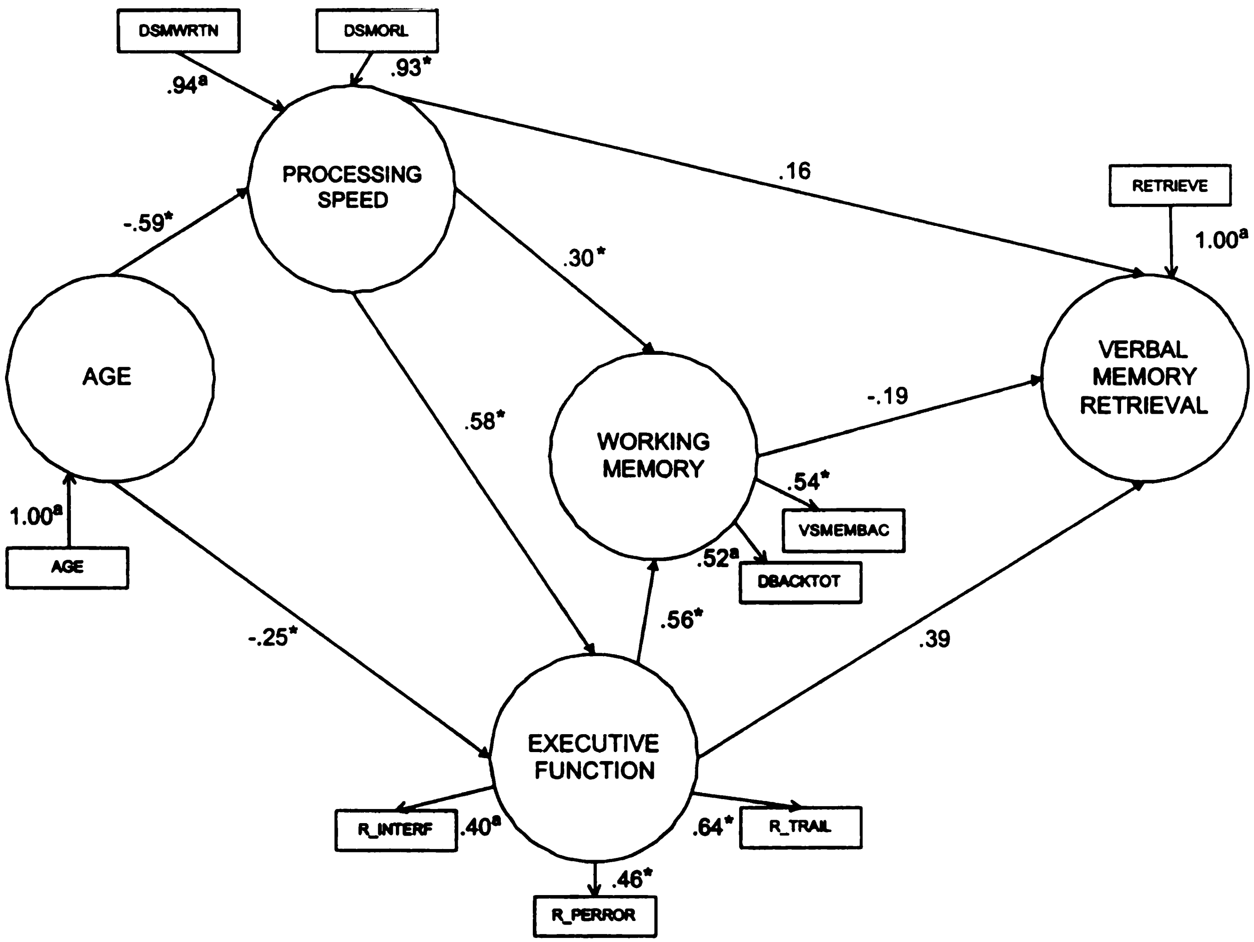
Notes. ª Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. * $p < .05$.

Figure 12. Completely standardized LISREL path coefficients and factor loadings associated with the model of no mediation of executive function in the age- related decline of verbal memory encoding, N = 304.



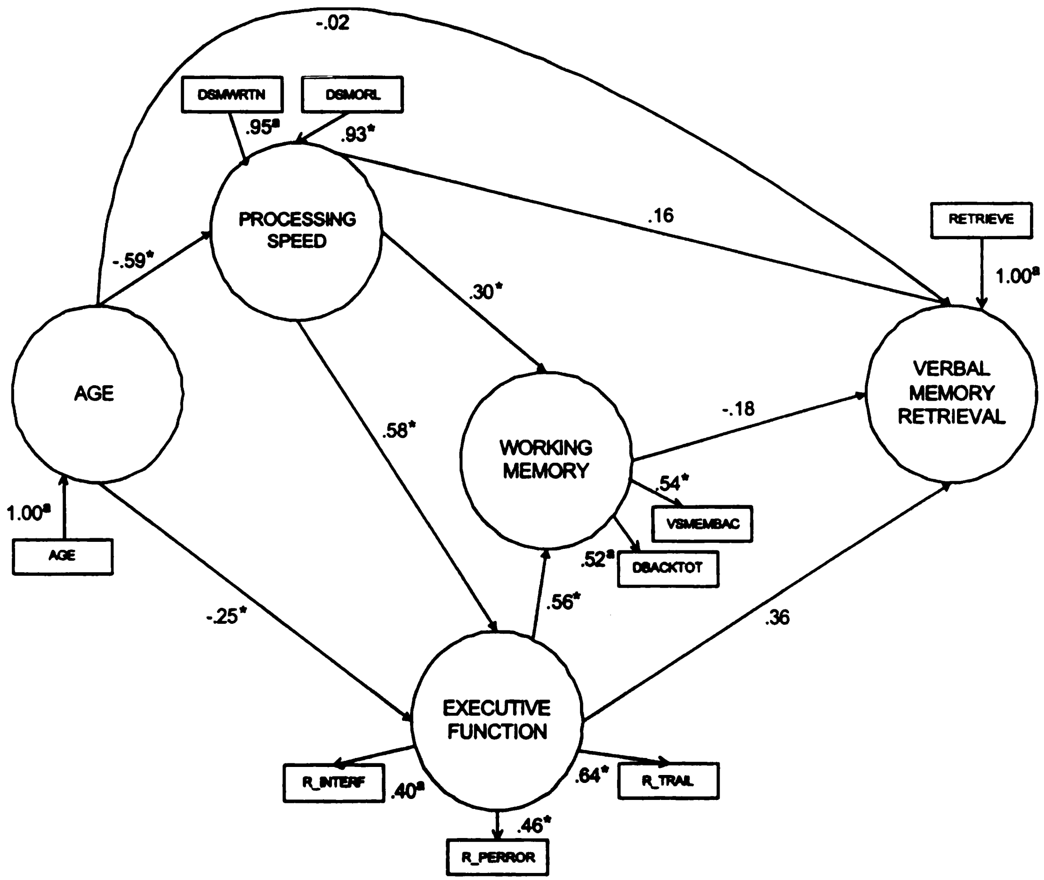
Notes. [a] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. $p < .05$.

Figure 13. Completely standardized LISREL path coefficients and factor loadings associated with model of age-related decline in verbal memory retrieval, N = 304



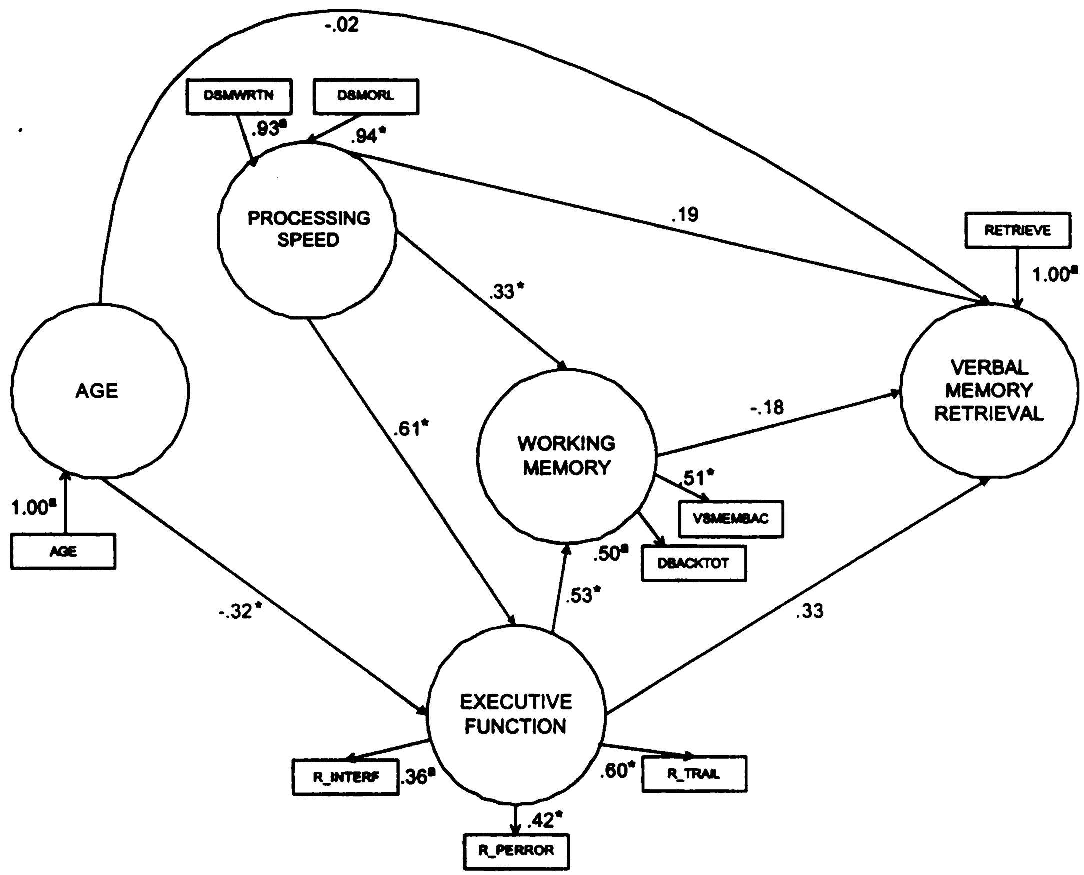
Notes. [a] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. * $p < .05$

Figure 14. Completely standardized LISREL path coefficients and factor loadings associated with complete path model of age-related decline in verbal memory retrieval, N = 304



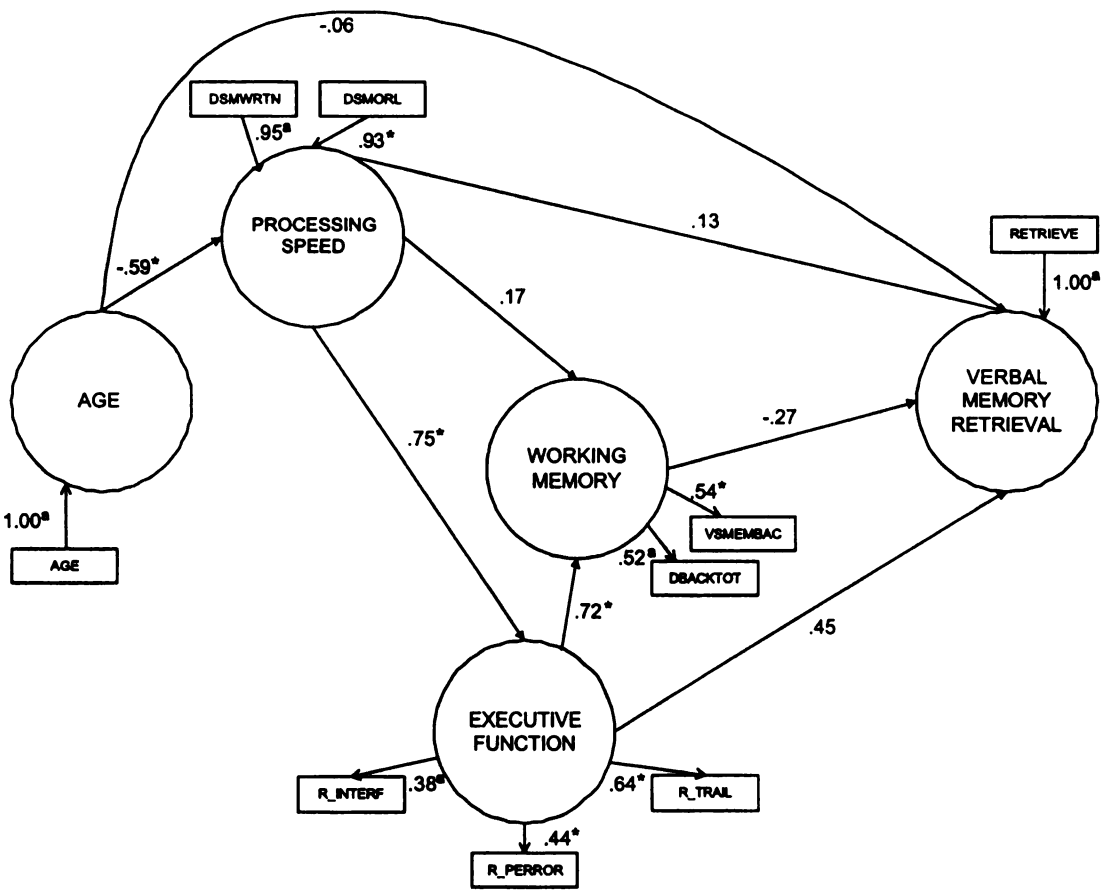
Notes. [a] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. * $p < .05$.

Figure 15. Completely standardized LISREL path coefficients and factor loadings associated with model of no mediation of processing speed in age-related decline of verbal memory retrieval, N = 304



Notes. [a] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. * p < .05.

Figure 16. Completely standardized LISREL path coefficients and factor loadings associated with model of no mediation of executive function in the age-related decline of verbal memory retrieval, N = 304



Notes. [a] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. * $p < .05$.

Figure 17. Common cause hierarchical model of age-related decline in verbal memory encoding

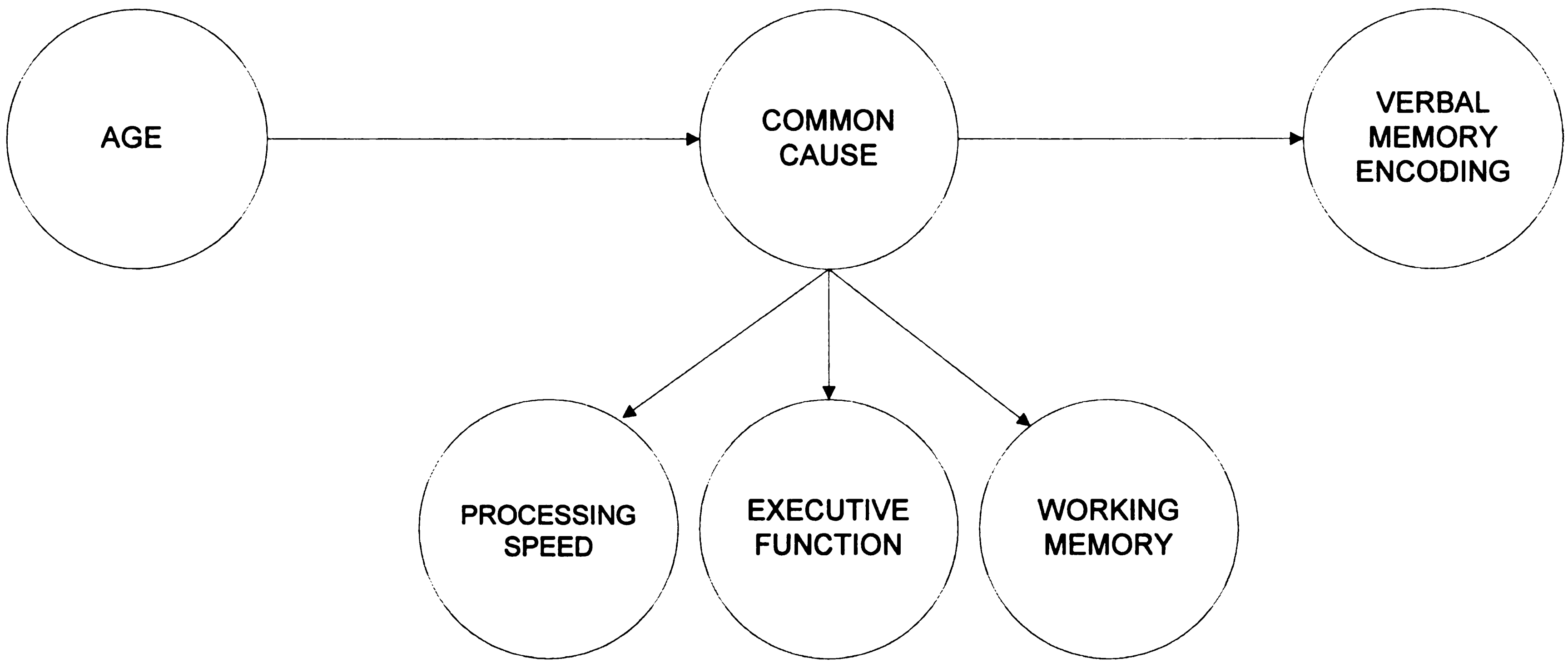


Figure 18. Common cause hierarchical model of age-related decline in verbal memory retrieval

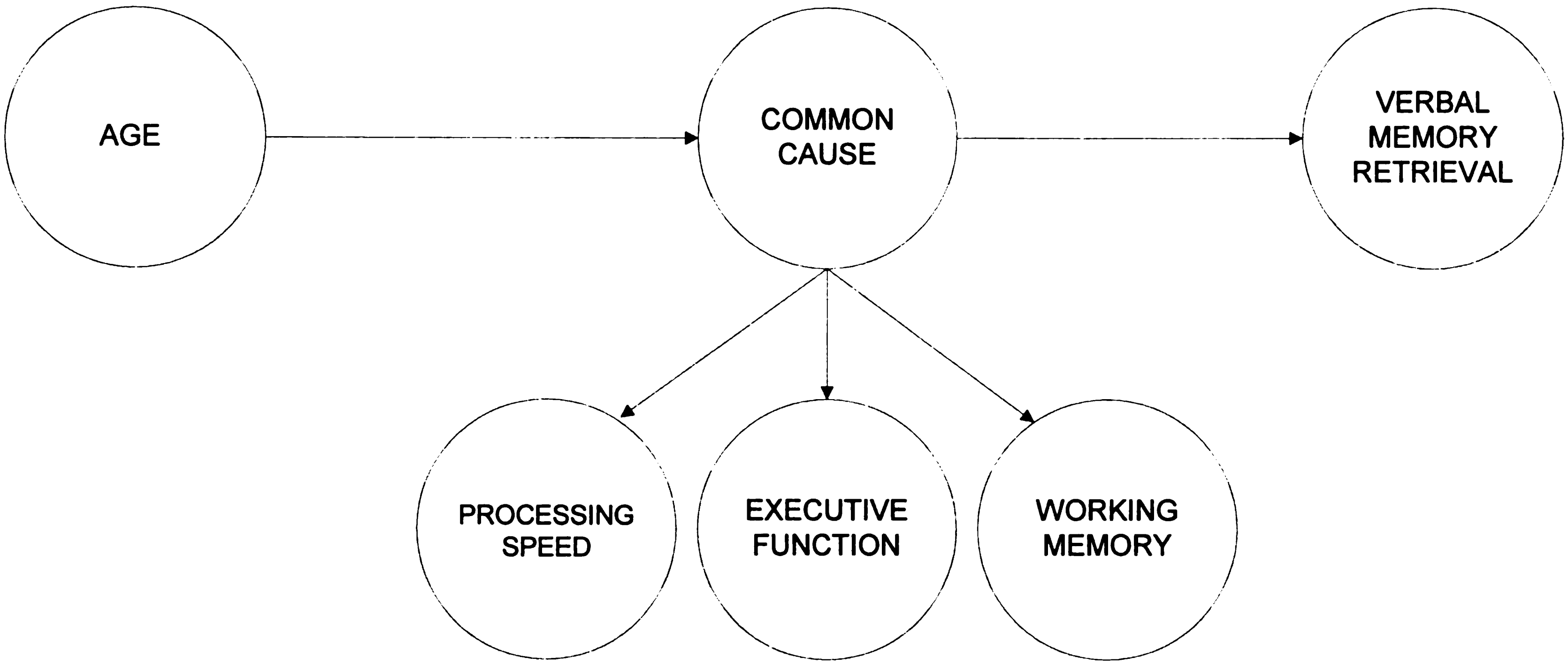
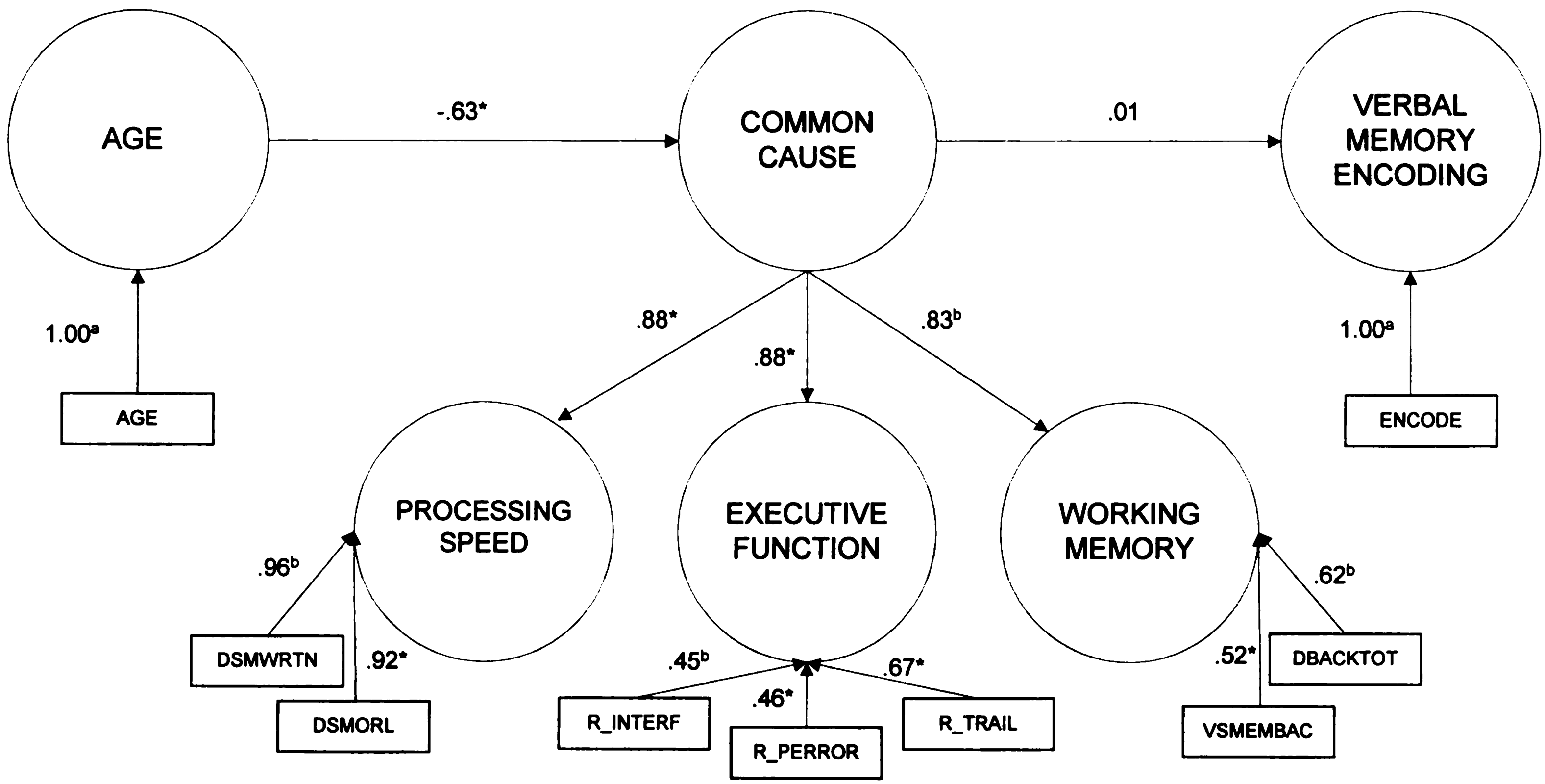
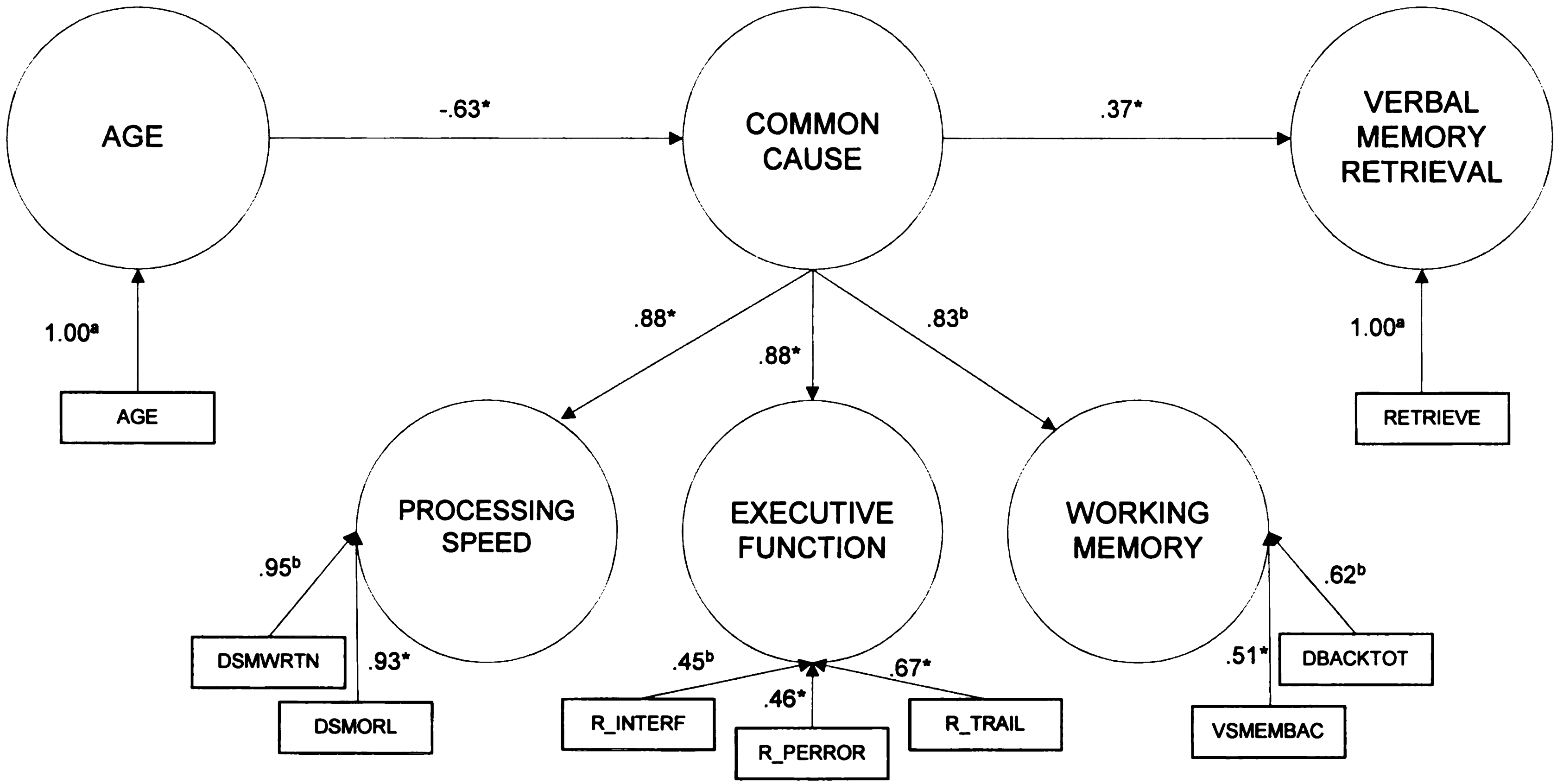


Figure 19. Completely standardized LISREL path coefficients and factor loadings associated with the common cause hierarchical model of age-related decline in verbal memory encoding, N = 304



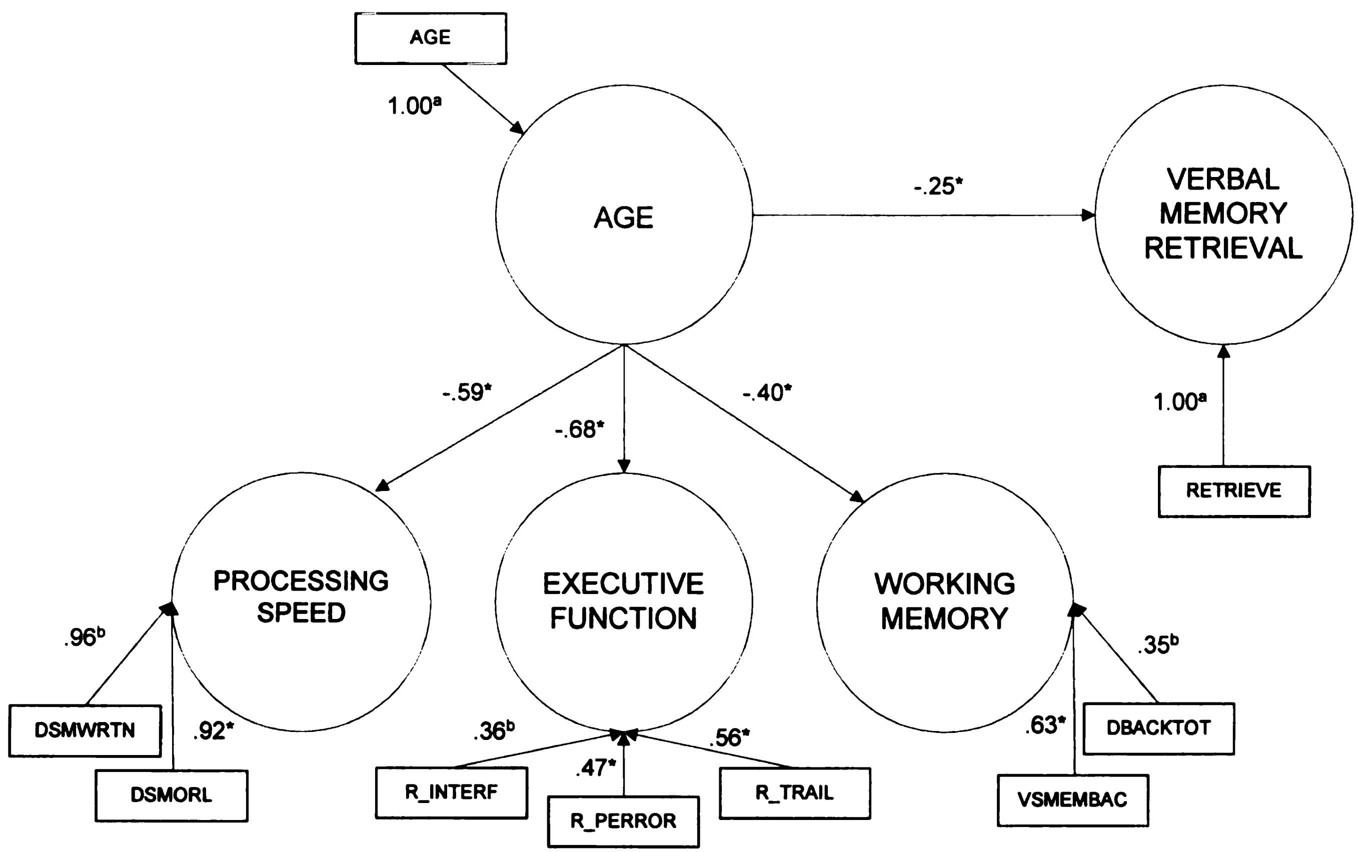
Notes. [a] These factor loadings were set to 1.00 because the variables were measured without error. For a detailed explanation of the factor loading for verbal memery encoding see the results section. [b] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. * $p < .05$.

Figure 20. Completely standardized LISREL path coefficients and factor loadings associated with the common cause hierarchical model of age-related decline in verbal memory retrieval, N = 304



Notes. [a] These factor loadings were set to 1.00 because the variables were measured without error. For a detailed explanation of the factor loading for verbal memory retrieval see the results section. [b] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors.* $p < .05$.

Figure 21. Completely standardized LISREL path coefficients and factor loadings associated with a model where age predicts all study variables, N = 304



Notes. [a] These factor loadings were set to 1.00 because the variables were measured without error. For a detailed explanation of the factor loading for verbal memory retrieval see the results section. [b] Significance tests were not obtained for the factor loadings of these indicator variables because they were used to scale the latent factors. * $p < .05$.

LIST OF REFERENCES

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Albert, M.S., & Kaplan, E. (1980). Organic implications of neuropsychological deficits in the elderly. In L.W. Poon, J.L. Fozard, L.S. Cermack. D. Arenberg, & L.W. Thompson (Eds.), *New directions in memory and aging: Proceedings of the George A. Talland Memorial Conference.* (pp. 403-432). Hillsdale: Erlbaum.

Anderson, S. W., Damasio, H., Jones, R. D., & Tranel, D. (1991). Wisconsin Card Sorting Test performance as a measure of frontal lobe damage. *Journal of Clinical and Consulting Psychology, 13,* 909-922.

Anderson, S.W., Jones, R.D., Tranel, A.P., Tranel, D., & Damasio, H. (1990). Is the Wisconsin Card Sorting Test an index of frontal lobe damage? *Journal of Clinical and Experimental Neuropsychology, 12,* 80 (Abstract).

Andres, P. & Van der Linden, M. (2000). Age-related difference in supervisory attentional system functions. *The Journals of Gerontology: Psychological Sciences and Social Sciences, Series B, 55B,* 373-380.

Arnett, P.A., Rao, S.M., Bernardin, L., Grafman, J., Yetkin, F.Z., & Lobeck, L. (1994). Relationship between frontal lobe lesions and Wisconsin Card Sorting Test performance in patients with multiple sclerosis. *Neurology, 44,* 420-425.

Axelrod, B. N., Goldman, R. S. & Henry, R. R. (1992). Sensitivity of the Mini-Mental State Examination to frontal lobe dysfunction in normal aging. *Journal of Clinical Psychology, 48,* 68-71.

Baddeley, A. (1986). *Working memory.* Oxford: Clarence Press.

Baddeley, A. (1990). *Human memory: Theory and practice.* London: Erlbaum.

Baddeley, A. (1998). The central executive: A concept and some misconceptions. *Journal of International Neuropsychological Society, 4,* 523-526.

Ball, K., Berch, D.B., Helmers, K.F., Jobe, J.B., Leveck, M.D., Marsiske, M., Mirrus, J.N., Rebok, G.W., Smith, D.M., Tennstedt, S.L., Unverzagt, F.W. & Willis, S.L. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *Journal of the American Medical Association, 288,* 2271-2281.

Balota, D.A., Dolan, P.O., & Duchek, J.M. (2000). Memory changes in healthy older adults. In E.Tulving & F.I.M. Craik (Eds.), *The Oxford Handbook of Memory.* (pp. 395-409). New York: Oxford University Press.

Baltes, P.B. & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging, 12,* 12-21.

Baron, R.M. & Kenny, D.A. (1986). The moderator-mediator variable distinction in social psychological research: Conceptual, strategic and statistical considerations. *Journal of Personality and Social Psychology, 51,* 1173-1182.

Beck, A. T. (1970). *Depression: Causes and Treatment.* Philadelphia: University of Pennsylvania Press.

Beck, A.T., & Beck, R.W. (1972). Screening depressed patients in family practice. *Postgraduate Medicine, 52,* 81-85.

Bentler, P.M. (1990). Comparative fit indexes in structural models. *Psychological Bulletin, 107,* 238-246.

Bentler, P.M. & Bonett, D.G. (1980). Significance tests and goodness of fit in the analysis of covariance structures. *Psychological Bulletin, 88,* 588-606.

Bentler, P.M. & Chou, C. (1987). Practical issues in structural modeling. *Sociological Methods and Research, 16,* 78-117.

Benton, A.L., Eslinger, P.J., & Damasio, A.R. (1981). Normative observations on neuropsychological test performances in old age. *Journal of Clinical Neuropsychology, 3,* 33-42.

Berman, K. F., Ostrem, J. L., Randolph, C., Gold, J., Goldberg, T. E., Coppola, R., Carson, R. E., Herscovitch, P., & Weinberger, D. R. (1995). Physiological activation of a cortical network during performance of the Wisconsin Card Sorting Test: A positron emission tomography study. *Neuropsychologica, 44,* 1027-1046.

Bielauskas, L. A. & Lamberty, G. J. (1992). Assessment of depression in elderly patients. *Clinical Neuropsychologist, 6,* 322.

Boone, K. B., Ghaffarian, S., Lesser, I. M., Hill-Gutierrez, E. & Berman, N. G. (1993). Wisconsin Card Sorting Test Performance in Healthy, Older Adults: Relationship to Age, Sex, Education, and IQ. *Journal of Clinical Psychology, 49,* 54-60.

Boone, K. B., Miller, B. L., Lesser, I. M., Hill, B. L., & D'Elia, L. (1990). Performance on frontal lobe tests in healthy, older individuals. *Developmental Neuropsychology, 6,* 215-223.

Boward, S. & Bell, R. (1992). Relative usefulness of the WMS and WMS-R: A comment on D'Elia et al. (1989). Journal of Clinical and Experimental Neuropsychology, 14, 340-346.

Brink, T.L., Yesavage, J.A., Lum, O., Heersema, P.H., Adey, M., & Rose, T.S. (1982). Screening tests for geriatric depression. *Clinical Gerontologist, 1,* 37-43.

Brown, C., Schulberg, H. C., & Madonia, M. J. (1995). Assessing Depression in Primary Care Practice with the Beck Depression Inventory and the Hamilton Rating Scale for Depression. *Psychological Assessment, 7,* 59-65.

Browne, M.W. & Cudeck, R. (1993). Alternative ways of assessing model fit. In K.A. Bollen & J.S. Long (Eds.), *Testing structural equation models* (pp.136-162). Newbury Park, CA: Sage Publications.

Bryan, J., & Luszcz, M.A. (1996). Speed of information processing as a mediator between age and free recall performance. *Psychology and aging, 11,* 3-9.

Bryan, J. & Luszcz, M.A. (2000). Measurement of executive function: Considerations for detecting adult age differences. *Journal of Clinical and Experimental Neuropsychology,22,* 40-55.

Bryan, J., Luszcz, M.A. & Pointer, S. (1999). Executive function and processing resources as mediators of adults age differences in the implementation of encoding strategies. *Aging, Neuropsychology and Cognition, 6,* 273-287.

Burgess, P.W. (1997). Theory and methodology in executive function research. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 81-116). UK: Psychology Press.

Burke, D.M. & Light, L.L. (1981). Memory and aging: The role of retrieval processes. *Psychological Bulletin, 90,* 513-516.

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging, 17,* 85-100.

Cabeza, R., Grady, C.L., Nyberg, L., McIntosh, A.R., Tulving, E., Kapur, S., Jennings, J.M., Houle, S., & Craik, F.I.M. (1997). Age-related difference in neural activity during memory encoding and retrieval: A positron emission tomography study. *Journal of Neuroscience, 17,* 391-400.

Cabeza, R. & Nyberg, L. (2000). Imaging cognition II: An empirical review of 275 PET and fMRI studies. *Journal of Cognitive Neuroscience, 12,* 1-47.

Campbell, J. I., & Charness, N. (1991). Age-related declines in working-memory skills: Evidence from a complex calculation task. *Developmental Psychology, 26,* 879-888.

Carlesimo, G.A., Fadda, L., Lorusso, S. & Caltagirone, C. (1994). Verbal and spatial memory spans in Alzheimer's and multi-in farct dementia. *Acta Neurologica Scandinavica, 89,* 132-138.

Carlesimo, G.A., Mauri, M., Graceffa, A.M.S., Fadda, L., Loasses, A., Lorusso, S. & Caltagirone, C. (1998) Memory performances in young, elderly, and very old healthy individuals versus patients with Alzheimer's Disease: Evidence for discontinuity between normal and pathological aging. *Journal of Clinical and Experimental Neuropsychology, 20,* 14-29.

Cellucci, T., Evans, W.J., Cattaruzza, C. & Carter, S. (2001). Stability and correlates of the California Verbal Learning Test for a sample of normal elderly persons. *Psychological Reports, 88,* 171-174.

Cerella, J. (1990). Aging and information-processing rate. In J. E. Birren & K. W. Shaie (Eds.). *Handbook of the Psychology of Aging 3rd edition.* (pp. 201-221). New York: Academic.

Charness, N. (1987). Component processes in bridge bidding and novel problem-solving tasks. *Canadian Journal of Psychology, 41,* 223-243.

Cohn, N.B., Dustman, R.E., & Bradford, D.C. (1984). Age-related decrements in Stroop Color Test performance. *Journal of Clinical Psychology, 40,* 1244-1250.

Coleman, P.D. & Flood, D.G. (1987). Neuron numbers and dendritic extent in normal aging and Alzheimer's Disease. *Neurobiology of Aging, 8,* 521-545.

Corcoran, R. & Upton, D. (1993). Role for the hippocampus in card sorting? *Cortex, 29*, 293-304.

Craik, F.I.M (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf (Eds.), *Human memory and cognitive capabilities, mechanisms and performance*. (pp.409-422). Amsterdam: Elsevier.

Craik, F.I.M., Anderson, N.D., Kerr, S.A., & Li, K.Z.H. (1995). Memory changes in normal ageing. In A.D. Baddeley & B.A. Wilson (Eds.), *Handbook of memory disorders* (pp.211-241). Chichester, England UK: John Wiley & Sons.

Craik, F.I.M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F.I.M. Craik, & S. Trehub (Eds.), *Aging and cognitive processes.* (pp. 191-211). New York: Plenum Press.

Craik, F.I.M., Givoni, R., Naveh-Benjamin, M. & Anderson, P.A. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology: General, 125,* 159-180.

Craik, F.I.M & Grady, C.L. (2002). Aging, memory, and frontal lobe functioning. In D.T. Stuss, & R.T. Knight (Eds.), *Principals of Frontal Lobe Function.* (pp. 528-540). New York: Oxford University Press.

Craik, F.I.M & Lockhart, R.S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11,* 671-684.

Craik, F.I.M., Morris, L.W., Morris, R.G., & Loewen, E.R. (1990). Relations between source amnesia and frontal lobe functioning in older adults. *Psychology and Aging, 5,* 148-151.

Crawford, J.R., Bryan, J., Luszcz, M.A., Obonsawin, M.C. & Stewart, L. (2000). The executive decline hypothesis of cognitive aging: Do executive deficits qualify as differential deficits and do they mediate age-related memory decline? *Aging, Neuropsychology and Cognition, 7,* 9-31.

Crowe, S. F. (1992). Dissociation of two frontal lobe syndromes by a test of verbal fluency. *Journal of Clinical and Experimental Neuropsychology, 14,* 327-339.

Crum, R. M., Anthony, J. C., Bassett, S. S. & Folstein, M. F. (1993). Population-based norms for the Mini-Mental State Examination by age and education level. *Journal of the American Medical Association, 269,* 2386-2391.

Curtiss, G., Vanderploeg, R.D., Spencer, J. & Salazar, A.M. (2001). Patterns of verbal learning and memory in traumatic brain injury. *Journal of International Neuropsychological Society, 7,* 574-585.

deLeon, M.J., George, A.E., Ferris, S.H., Christman, D.R., Fowler, J.S., Gentes, C., Brodie, J, Reisberg, B & Wolf, A.P. (1984). Positron emission tomography and computed tomography assessments of the aging human brain. *Journal of Computer Assisted Tomography, 8,* 88-94.

Delis, D. C., Freeland, J., Kramer, J. H., & Kaplan, E. (1988). Integrating clinical assessment with cognitive neuroscience: Construct validation of the California Verbal Learning Test. *Journal of Consulting and Clinical Psychology, 56,* 123-130.

Delis, D.C., Kramer, J.H., Kaplan, E., & Ober, B.A. (1987). *California Verbal Learning Test: Adult Version Manual.* San Antonio, TX: The Psychological Corporation.

Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review, 12,* 45-75.

Diagneault, S., Braun, C. M. J. (1993). Working memory and the Self-Ordered Pointing Task: Further evidence of early prefrontal decline in normal aging. *Journal of Clinical and Experimental Neuropsychology, 15,* 881-895.

Diagneault, S., Braun, C. M. J., Witaker, H. A. (1992). Early effects of normal aging on perseverative and non-perseverative prefrontal measures. *Developmental Neuropsychology, 8,* 99-114.

Duchnick, J.J., Vanderploeg, R.D. & Curtiss, G. (2002). Identifying retrieval problems using the California Verbal Learning Test. *Journal of Clinical and Experimental Neuropsychology, 24*, 840-851.

Dunlosky, J & Hertzog, C. (1998). Aging and deficits in associative memory: What is the role of strategy production? *Psychology and Aging, 13,* 597-607.

Fabiani, M., Friedman, D. & Cheng, J.C. (1998). Individual difference in P3 scalp distribution in older adults and their relationships to frontal lobe function. *Psychophysiology, 35,* 698-708.

Ferrer-Caja, E., Crawford, J.R. & Bryan, J. (2002). A structural modeling examination of the executive decline hypothesis of cognitive aging through reanalysis of Crawford et al.'s (2000) data. *Aging, Neuropsychology and Cognition, 9,* 231-249.

Fisk, J.E. & Warr, P. (1996). Age and working memory: The role of perceptual speed, the central executive, and the phonological loop. *Psychology and Aging, 11,* 316-323.

Fletcher, P.C., Shallice, T., Frith, C.D., Frackowiak, R.S. & Dolan, R.J. (1998). The functional roles of prefrontal cortex in episodic memory, II. Retrieval. *Brain, 121,* 1249-1256.

Folstein, M.F., Folstein, S.E., & McHugh, P.R. (1975). 'Mini-mental State'. A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189-198.

Foos, P. W. (1989). Adult age differences in working memory. *Psychology and Aging, 4*, 269-275.

Foster, J. R., Sclan, S., Welkowitz, J., Boksay, I. & Seeland, I. (1988). Psychiatric assessment in medical long-term care facilities: Reliability of commonly used rating scales. *International Journal of Geriatric Psychiatry, 3,* 229-233.

Fuster, J.M. (1989). *The prefrontal cortex, 2nd edition.* New York: Raven Press.

Golden, J.C. (1978). *Stroop Color and Word Test.* Chicago, IL: Stoelting Company.

Golski, S., Zonderman, A.B., Malamut, B.L., & Resnick, S.M. (1998). Verbal and figural recognition memory: Task development and age associations. *Experimental Aging Research, 24,* 359-385.

Greenwood, P.M. (2000). The frontal aging hypothesis evaluated. *Journal of the International Neuropsychological Society, 6,* 705-726.

Grady, C.L., Bernstein, L., Siegenthaler, A., & Beig, S. (2002). The effects of encoding strategy on age-related difference in the functional neuroanatomy of face memory. *Psychology and Aging, 17,* 7-23.

Grady, C.L., McIntosh, A.R., Horwitz, B., Maisog, J.M., Ungerleider, L.G., Mentis, M.J., Pietrini, P., Schapiro, M.B., & Haxby, J.V. (1995). Age-related reductions in human recognition memory due to impaired encoding. *Science, 269,* 218-221.

Grober, E., & Sliwinski, M. (1991). Development and validation of a model for estimating premorbid verbal intelligence in the elderly. *Journal of Clinical and Experimental Neuropsychology, 13,* 933-949.

Gronwall, D. (1989). Cumulative and persisting effects of concussion on attention and cognition. In H.S. Levin, H.M. Eisenberg, & A.L. Benton (Eds.), *Mid head injury* (pp. 355-371). New York: Oxford University Press.

Haaland, K.Y., Vranes, L.F., Goodwin, J.S., & Garry, P.J. (1987). Wisconsin Card Sort Test performance in a healthy elderly population. *Journal of Gerontology, 33,* 345-346.

Hamilton, M. (1967). Development of a rating scale for primary depressive illness. *British Journal of Social and Clinical Psychology, 6,* 278-296.

Hanley, J.R., Davies, A.D.M., Downes, J.J. & Mayes, A.R. (1994). Impaired recall of verbal material following rupture and repair of an anterior communicating artery aneurysm. *Cognitive Neuropsychology, 11,* 543-578.

Hanninen, T., Hallikainen, M., Koivisto, K., Partanen, K., Laakso, M.P., Riekkinen, P.J., & Soininen, H. (1997). Decline of frontal lobe functions in subjects with age associated memory impairment. *Neurology, 48,* 148-153.

Hartley, J. T. (1986). Reader and text variables as determinants of discourse memory in adulthood. *Psychology and Aging, 1,* 150-158.

Hartley, J. T. (1993). Aging and prose memory: Tests of the resource-deficit hypothesis. *Psychology and Aging, 8,* 538-551.

Hasher, L. & Zacks, R. (1988). Working memory, comprehension and aging: A review and a new view. *The Psychology of Learning and Motivation, 22,* 193-225.

Haug, H., Barmwater, U., Eggers, R. Fischer, D., Kuhl, S., & Sass, N.L. (1983). Anatomical changes in the aging brain: Morphometric analysis of the human prosencephalon. In J. Cervos-Navarro & H.I. Sarkander (Eds.). *Brain aging: Neuropathology and neuropharmacology.* (Vol 21). New York: Raven Press.

Hayduk, L.A. (1987). *Structural equation modeling with LISREL: Essentials and advances.* Baltimore: Johns Hopkins University Press.

Heaton, R.K. (1981). *Wisconsin Card Sorting Test Manual.* Odessa, FL: Psychological Assessment Resources, Inc.

Hertzog, C. (1985). Applications of confirmatory factor analysis to the study of intelligence. *Current Topics in Human Intelligence, 1,* 59-97.

Hertzog, C. (1987). Applications of structural equation models in gerontological research. In K.W. Schaie (Ed.), *Annual review of gerontology and geriatrics* (Vol 7, pp. 265-293). New York: Springer.

Hertzog, C. (1990). On the utility of structural equation models for developmental research. In P.B. Baltes, D.L. Featherman, & R.M. Lerner (Eds.), *Life-span development and behavior* (Vol. 10. pp. 257-290). Hillsdale, NJ: Erlbaum.

Holst, P. & Vilkki, J. (1988). Effect of frontomedial lesions on performance on the Stroop Test and word fluency tasks. *Journal of Clinical and Experimental Neuropsychology, 10,* 79 (Abstract).

Horn, J.L. & McArdle, J.J. (1980). Perspectives on mathematical/statistical model building (MASMOB) in research on aging. In L.W. Poon (Ed.), *Aging in the 1980s: Psychological issues* (pp. 503-541). Washington, DC: American Psychological Association.

Houx, P. J., Jolles, J. Vreeling, F. W. (1993). Stroop interference: Aging effects assessed with the Stroop Color-Word Test. *Experimental Aging Research, 19,* 209-224.

Hultsch, D.F., Hertzog, C., & Dixon, R.A. (1990). Ability correlates of memory performance in adulthood and aging. *Psychology and aging, 5,* 356-368.

Hultsch, D.F., Hertzog, C., Dixon, R.A. & Small, B.J. (1998). *Memory changes in the aged.* UK: Cambridge University Press.

Hultsch, D.F., Hertzog, C., Small, B.J., McDonald-Miszczak, L. & Dixon, R.A. (1992). Short term longitudinal change in cognitive performance in later life. *Psychology and Aging, 7,* 571-584.

Incisa della Rochetta, A. (1986). Classification and recall of pictures after unilateral frontal of temporal lobectomy. *Cortex, 22,* 189-211.

Johnson, S.C., Saykin, A.J., Flashman, L.A., McAllister, T.W. & Sparling, M.B. (2001). Brain activation on fMRI and verbal memory ability: Functional neuroanatomic correlates of CVLT performance. *Journal of the International Neuropsychological Society, 7,* 55-62.

Johnstone, B., Slaughter, J., Schopp, L., McAllister, J.A., Schwake, C. & Luebbering, A. (1997). Determining neuropsychological impairment using estimates of premorbid intelligence: Comparing methods based on level of education versus reading scores. *Archives of Clinical Neuropsychology, 12,* 591-601.

Joreskog, K. & Sörbom, D. (1986). *LISREL 6: Analysis of linear structural relationships by maximum likelihood and least square methods.* Mooresville, IN: Scientific Software.

Joreskog, K. & Sörbom, D. (1989). *LISREL 7: A guide to the program and application (2nd ed.).* Chicago: SPSS.

Joreskog, K. & Sörbom, D. (1993). *LISREL 8: Structural equation modeling with the SIMPLIS command language.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Kail, R. & Salthouse, T. A. (1994). Processing speed as a mental capacity. *Acta Psychologica, 86,* 199-225.

Kennedy, K. J. (1981). Age effects on Trail Making Test performance. *Perceptual and Motor Skills, 52,* 671-675.

Kliegl, R., Smith, J. & Baltes, P.B. (1989). Testing-the-limits and the study of adult age differences in cognitive plasticity of a mnemonic skill. *Developmental Psychology, 25,* 247-256.

Koenig, H. G., Meador, K. G., Cohen, H. J. & Blazer, D. G. (1988). Self-rated depression scales and screening for major depression in older hospitalized patients with medical illnesses. *Journal of the American Geriatrics Society, 36,* 699-796.

Leach, L.R., Warner, C.M., Hotz-Sud, R., Kaplan, E., & Freedman, M. (1991). The effects of age on Wisconsin Card Sorting variables. *Journal of Clinical and Experimental Neuropsychoogy, 13,* 28 (Abstract).

Lepage, M., Habib, R. & Tulving, E. (1998). Hippocampal PET activations of memory encoding and retrieval: The HIPER model. *Hippocampus, 8,* 313-322.

Lezak, M.D. (1995). *Neuropsychological Assessment, 3rd edition.* New York: Oxford University Press.

Light, L.L. (1991). Memory and aging: Four hypotheses in search of data. *Annual Review of Psychology, 42,* 333-376.

Light, L.L. & Anderson, P.A. (1985). Working memory capacity, age, and memory for discourse. *Journal of Gerontology, 40,* 737-747.

Lindenberger, U & Baltes, P.B. (1994). Sensory functioning and intelligence in old age: A strong connection. *Psychology and Aging, 9,* 339-355.

Lindenberger, U., Mayr, U., & Kliegl, R. (1993). Speed and intelligence in old age. *Psychology and Aging, 8,* 207-220.

Lowe, C. & Rabbitt, P. (1997). Cognitive models of aging and frontal lobe deficits. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 39-59). UK: Psychology Press.

Luszcz, M.A. (1992). Mediators of memory in young-old and old-old adults. *International Journal of Behavioral Development,15,* 147-166.

Luszcz, M. A. & Bryan, J. (1999). Toward understanding age-related memory loss in late adulthood. *Gerontology, 45,* 2-9.

Macleod, C.M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109,* 163-203.

Mamo, H., Meric, P., Luft, A., & Seylaz, J. (1983). Hyperfrontal pattern of human cerebral circulation: Variations with age and arteriosclerotic state. *Archives of Neurology, 40,* 626-632.

Mayr, U., & Kliegl, R. (1993). Sequential and coordinative complexity: Age-based processing limitations and figural transformations. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 19,* 1297 – 1320.

Mejia, S., Pineda, D., Alvarez, L.M. & Ardila, A. (1998). Individual differences in memory and executive function abilities during normal aging. *International Journal of Neuroscience, 95,* 271-284.

Milner, B. (1964). Some effects of frontal lobectomy in man. In J.M. Warren & K. Akert (Eds.). *The frontal granular cortex and behavior.* New York: McGraw Hill.

Milner, B., Petrides, M., & Smith, M.L. (1985). Frontal lobes and the temporal organization of memory. *Human Neurobiology, 4,* 137-142.

Mitrushina, M. & Satz, P. (1991). Reliability and validity of the Mini-Mental State Exam in neurologically intact elderly. *Journal of Clinical Psychology, 47,* 537-543.

Mittenberg, W., Seidenberg, M., O'Leary, D. S. & DiGuilo, D. V. (1989). Changes in cerebral functioning associated with normal aging. *Journal of Clinical and Experimental Neuropsychology, 11,* 918-932.

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A. & Wager, T.D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49-100.

Morris, R.G. (1994). Working memory in Alzheimer-type dementia. *Neuropsychology, 8,* 544-554.

Moscovitch, M. (1989). Confabulation and the frontal system: Strategic vs. associative retrieval in neuropsychological theories of memory. In H.L. Roediger III & F.I.M. Craik (Eds.). *Varieties of memory and consciousness: Essays in honor of Endel Tulving.* Hillsdale NJ: Erlbaum.

Moscovitch, M. & Winocur, G. (1992). The neuropsychology of memory and aging. In F.I.M. Craik, & T.A. Salthouse (Eds.), *The handbook of aging and cognition.* Hillsdale: Erlbaum.

Moscovitch, M. & Winocur, G. (1995). Frontal lobes, memory, and aging. *Annals of the New York Academy of Sciences, 769,* 119-150.

Moscovitch, M. & Winocur, G. (2002). The frontal cortex and working with memory. In D.T. Stuss & R.T. Knight (Eds.), *Principles of frontal lobe function.* (pp. 188-209). New York: Oxford University Press.

Moscovitch, M. & Umilta, C. (1990). Modularity and neuropsychology: Implications for the organization of attention and memory in normal and brain-damaged people. In M. E. Schwartz (Ed.), *Modular processes in dementia.* Cambridge, MA: MIT Press/Bradford.

Moscovitch, M. & Umilta, C. (1991). Conscious and nonconscious aspects of memory: A neuropsychological framework of modules and central systems. In R.G. Lister & H.J. Weingartner (Eds.), *Perspectives on cognitive neuroscience.* Oxford, England: Oxford University Press.

Mountain, M.A. & Snow, W.G. (1993). Wisconsin Card Sorting Test as a measure of frontal pathology: A review. *The Clinical Neuropsychologist, 7,* 108-118.

Nathan, J., Wilkinson, D., Stammers, S., & Low, J.L. (2001). The role of tests of frontal executive function in the detection of mild dementia. *International Journal of Geriatric Psychiatry, 16,* 18-26.

Nettelbeck, T. & Rabbitt, P.M.A. (1992). Aging, cognitive performance, and mental speed. *Intelligence, 16,* 189-205.

Nielson, K.A., Langenecker, S.A. & Garavan, H. (2002). Differences in the functional neuroanatomy of inhibitory control across the adult life span. *Psychology and Aging, 17,* 56-71.

Nyberg, L., Cabeza, R. & Tulving, E. (1996). PET studies of encoding and retrieval: The HERA model. *Pyschonomic Bulletin & Review, 3,* 135-148.

Nyberg, L., Cabeza, R. & Tulving, E. (1998). Asymmetric frontal activation during episodic memory: What kind of specificity? *Trends in Cognitive Sciences, 2,* 419-420.

Paolo, A.M., Troster, A.I., & Ryan, J.J. (1997a). California Verbal Learning Test: Normative data for the elderly. *Journal of Clinical and Experimental Neuropsychology, 19,* 220-234.

Paolo, A.M., Troster, A.I. & Ryan, J.J. (1997b). Test-retest stability of the California Verbal Learning Test in older person. *Neuropsychology, 11,* 613-616.

Park, D.C., Smith, A.D., Lautenschlager, G., Earles, J.L., Frieske, D., Zwahr, M., & Gaines, C.L. (1996). Mediators of long-term memory performance across the life span. *Psychology and aging, 11,* 621-637.

Parkin, A.J. (1996). *Explorations in cognitive neuropsychology.* Oxford: Blackwell.

Parkin, A.J. (1998). The central executive does not exist. *Journal of the International Neuropsychological Society, 4,* 518-522.

Parkin, A.J. & Lawrence, A. (1994). A dissociation in the relation between memory tasks and frontal lobe tests in the normal elderly. *Neuropsychologia, 32,* 1523-1532.

Parkin, A.J. & Walter, B.M. (1991). Aging, short-term memory, and frontal dysfunction. *Psychobiology, 19,* 175-179.

Parkin, A.J. & Walter, B.M. (1992). Recollective experience, normal aging, and frontal dysfunction. *Psychology and Aging, 7,* 290-298.

Parkin, A.J., Yeomans, J. & Bindschaedler, C. (1994). Further characterization of the executive memory impairment following frontal lobe lesions. *Brain and Cognition, 26,* 23-42.

Parmelee, P.A., Lawton, M.P. & Katz, I.R. (1989). Psychometric properties of the Geriatric Depression Scale among the institutionalized aged. *Psychological Assessment, 1,* 331-338.

Perret. E. (1974). The left frontal love of man and the suppression of habitual responses in verbal categorical behaviour. *Neuropsychologica, 12,* 323-330.

Petrides, M., Alivisatos, B., Evans, A.C. & Meyer, E. (1993). Dissociation of human mid dorsolateral from posterior dorsolateral frontal cortex in memory processing. *Proceedings of the National Academy of Science, 90,* 873-877.

Petrides, M., Alivisatos, B., Meyer, E. & Evans, A.C. (1993). Functional activation of the human frontal cortex during the performance of verbal working memory tasks. *Proceedings of the National Academy of Science, 90,* 878-882.

Petrides, M. & Milner, B. (1982). Deficits on subject-ordered tasks after frontal and temporal lobe lesions in man. *Neuropsychologica, 20,* 249-262.

Picton, P.W., Stuss, D.T., & Marshall, K.C. (1986). Attention and the brain. In S.L. Friedman, K.A. Klivington, & R.W. Petersen (Eds.), *The brain, cognition, and education.* (pp.19-79). New York: Academic Press.

Ponsford, J. & Kinsella, G. (1993). Attentional deficits following closed-head injury. *Journal of Clinical and Experimental Neuropsychology, 14,* 822-838.

Poon, L.W. (1985). Differences in human memory with aging: Nature, causes, and clinical implications. In J.E. Birren & K.W. Schaie (Eds.). *Handbook of the psychology of aging, 2nd edition.* New York: Van Nostrand Reinhold.

Prigatano, G. (1978). Wechsler Memory Scale: A selective review of the literature.

Journal of Clinical Psychology, 34, 816-832.

Rabbitt, P. (1997). Introduction: Methodologies and models in the study of executive function. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 1-38). UK: Psychology Press.

Rabinowitz, J.C. (1984). Age and recognition failure. *Journal of Gerontology, 39,* 65 71.

Ragland, J.D., Glahn, D.C., Gur, R.C., Censits, D.M., Smith, R.J., Mozley, R.D., Alavi, A & Gur, R.E. (1997). PET regional cerebral blood flow change during working and declarative memory: Relationship with task performance. *Neuropsychology, 11,* 222-231.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F.I.M. Craik & T.A. Salthouse (Eds.), *The Handbook of Aging and Cognition, 2nd edition.* (pp.1-90). Mahwah, NJ: Lawrence Erlbaum Associates.

Raz, N., Gunning, F., Head, D.P., Briggs, S.D., Dupuis, J.H., McQuain, J., Loken, W.J., Thornton, A.E., & Ackers, J.D. (1995). In search of neuroanatomical substrates of memory and executive abilities: Aging as a model system. *Soc. Neuroscience Abstracts, 21,* 195-914.

Raz, N., Head, D.P., Gunning, F., & Ackers, J.D. (1996). *Neural correlates of working memory and strategic flexibility: A double dissociation study.* Paper presented at meeting of the International Neuropsychological Society.

Raz, N., Torres, I.J., Spencer, W.D. & Acker, J.D. (1993). Pathoclysis in aging human cerebral cortex: Evidence from in vivo MRI morphometry. *Psychobiology, 21,* 151-60.

Reitan, R. M. (1958). Validity of the Trail Making Test as an Indicator of Organic Brain Damage. *Perceptual and Motor Skills, 8,* 271-276.

Reitan, R.M. & Wolfson, D. (1994). A selective and critical review of neuropsychological deficits and the frontal lobes. *Neuropsychology Review, 4,* 161-198.

Reitan, R.M. & Wolfson, D. (1995). Category test and trail making test as measures of frontal lobe functions. *The Clinical Neuropsychologist, 9,* 50-56.

Reynolds, W. M. & Gould, J. W. (1981). A Psychometric Investigation of the Standard and Short form Beck Depression Inventory. *Journal of Consulting and Clinical Psychology, 49,* 306-307.

Rezai, K., Anderson, N.C., Alliger, R., Cohen, G., Swayze II, V., & O'Leary, D.S. (1993). The neuropsychology of the prefrontal cortex. *Archives of Neurology, 50,* 636-642.

Rubin, D.C. (1999). Frontal-striatal circuits in cognitive aging: Evidence for caudate involvement. *Aging, Neuropsychology and Cognition, 6,* 241-259.

Salthouse, T.A. (1980). Age and memory: Strategies for localizing the loss. In L.W. Poon, J.L. Fozard, L. Cermack, D. Arenberg, & L.W. Thompson (Eds.), *New directions in memory and aging.* (pp. 47-65). Hillsdale: Lawrence Erlbaum.

Salthouse, T.A. (1985). *A theory of cognitive aging.* Amsterdam: North Holland.

Salthouse, T.A. (1988). Resource-reduction interpretations of cognitive aging. *Developmental Review, 8,* 238-272.

Salthouse, T.A. (1991). *Theoretical perspectives on cognitive aging.* Hillsdale, NJ: Erlbaum.

Salthouse, T.A. (1992a). Influence of processing speed on adult age difference in working memory. *Acta Psychologica, 79,* 155-170.

Salthouse, T.A. (1992b). What do adult age differences in the Digit Symbol Substitution Test reflect? *Journal of Gerontology: Psychological Sciences, 47,* 121-128.

Salthouse, T.A. (1993). Speed mediation of adult age differences in cognition. *Developmental Psychology, 29,* 722-738.

Salthouse, T. A. (1994). The nature of the influence of speed on adult age differences in cognition. *Developmental Psychology, 30,* 240-259.

Salthouse, T.A. (1996a). General and specific speed mediation of adult age differences in memory. *Journals of Gerontology Series B, Psychological Sciences, & Social Sciences, 51,* 30-42.

Salthouse, T. A. (1996b). The processing-speed theory of adult age differences in cognition. *Psychological Review, 10,* 403-428.

Salthouse, T.A. (2001). Structural models of the relations between age and measure of cognitive functioning. *Intelligence, 29,* 93-115.

Salthouse, T. A. & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology, 27,* 763-776.

Salthouse, T.A. & Czaja, S.J. (2000). Structural constraints on process explanations in cognitive aging. *Psychology and Aging, 15,* 44-55.

Salthouse, T.A. & Ferrer-Caja, E. (2003). What needs to be explained to account for age-related effects on multiple cognitive variables? *Psychology and Aging, 18,* 91-110.

Salthouse, T. A., Fristoe, N. & Rhee, S.H. (1996). How localized are age-related effects on neuropsychological measures? *Neuropsychology, 10,* 272-285.

Salthouse, T.A., Kausler, D.H., & Saults, J.S. (1988). Utilization of path-analytic procedures to investigate the role of processing resources in cognitive aging. *Psychology and Aging, 3,* 158-166.

Schacter, D.L., Harbluck, J.L. & Mclachlan, D.R. (1984). Retrieval without recollection: An experimental analysis of source amnesia. *Journal of Verbal Learning and Verbal Behavior, 23,* 593-611.

Schaefer, A., Brown, J. & Watson, C. G. (1985). Comparison of the Validities of the Beck, Zung, and MMPI Depression Scales. *Journal of Consulting and Clinical Psychology, 53,* 415-418.

Schafer, J.L. (1997). *Analysis of incomplete multivariate data.* London: Chapman & Hall.

Schaie, K. W. (1989). Perceptual speed in adulthood: Cross-sectional and longitudinal studies. *Psychology and Aging, 4,* 443-453.

Schaie, K. W. (1994). The course of adult intellectual development. *American Psychologist, 49,* 304-313.

Schaie, K.W. & Hertzog, C. (1985). Measurement in the psychology of adulthood and aging. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology of aging* (2nd ed., pp. 61-92). New York: Van Nostrand Reinhold.

Schumacher, E.H., Lauber, E., Awh, E., Jonides, J. & Smith, E.E. (1996). PET evidence of an amodal verbal working memory system. *Neuroimage, 3,* 383-394.

Shimamura, A. P. (1990). Aging and memory disorders: A neuropsychological analysis. In M.L. Howe, M.J. Stones, & C.J. Brainerd (Eds.), *Cognitive and Behavioral Performance Factors in Atypical Aging.* (pp. 37-65). New York: Springer.

Shimamura, A.P. (1995). Memory and frontal lobe function. In M.S. Gazzaniga (Ed.). *The cognitive neurosciences.* (pp.803-813). Cambridge MA: MIT press.

Shimamura, A. P. & Jurica, P. J. (1994). Memory interference effects and aging: Findings from a test of frontal lobe function. *Neuropsychology, 8,* 408-412.

Shimamura, A.P., Janowsky, J.S., & Squire, L.R. (1991). What is the role of frontal lobe damage in memory disorders? In H.S. Levin, H.M. Eisenberg, & A. L. Benton (Eds.), *Frontal Lobe Function and Dysfunction.* (pp. 173-195) NewYork: Oxford University Press.

Smith, A. (1991). *Symbol Digit Modalities Test.* Los Angeles: Western Psychological Services.

Spencer, W.D. & Raz, N. (1994). Memory for facts, source, and context: Can frontal lobe dysfunction explain age-related differences? *Psychology and Aging, 9,* 149-159.

Spreen, O., & Strauss, E. (1998). *A compendium of neuropsychological tests: Administration, norms, and commentary, 2nd edition.* New York: Oxford University Press.

Squire, L.R. (1982). Comparisons between forms of amnesia: Some deficits are unique to Korsakoff's syndrome. *Journal of Experimental Psychology: Learning , Memory and Cognition, 8,* 560-571.

Squire, L.R. (1987). *Memory and brain.* New York: Oxford University Press.

Stebbins, G.T., Carrillo, M.C., Dorfman, J., Dirksen, C., Desmond, J.E., Turner, D.A., Bennett, D.A., Wilson, R.S., Glover, G. & Gabrieli, J.D.E. (2002). Aging effects on memory encoding in the frontal lobes. *Psychology and Aging, 17,* 44-55.

Steiger, J.H. (1990). Structural model evaluation and modification: An interval estimation approach. *Multivariate Behavioral Research, 25,* 173-180.

Stuss, D.T., Alexander, M.P., Floden, D., Binns, M.A., Levine, B., McIntosh, A.R., Rajah, N., & Hevenor, S.J. (2002). Fractionation and localization of distinct frontal lobe processes: Evidence from focal lesions in humans. In D.T. Stuss and R.T. Knight (Eds.), *Principles of frontal lobe function.* (pp. 392-407). New York: Oxford University Press.

Stuss, D.T. & Benson, D.F. (1986). *The frontal lobes.* New York: Raven Press.

Stuss, D.T., Craik, F.I.M, Sayer, L., Franchi, D., & Alexander, M.P. (1996). Comparison of older people with patients with frontal lesions: Evidence from word list learning. *Psychology and Aging, 11,* 387-539.

Stuss, D.T., Kaplan, E.F., Benson, D.F., Weir, W.S., Chiuli, S. & Sarazin, F.F. (1982). Evidence for the involvement of orbitofrontal cortex in memory functions: An interference effect. *Journal of Comparative and Physiological Psychology, 96,* 913-925.

Tabachnick, B.G. & Fidell, L.S. (1996). *Using multivariate statistics, 3rd edition.* New York, NY: Harper Collins College Publishers.

Tachibana, H., Meyer, J.S., Okayasu, H. & Kandula, P. (1984). Changing topographic patterns of human cerebral blood flow with age measured by xenon CT. *American Journal of Roentgenology, 142,* 1027-1034.

Toros, M.M. (2001). Frontal components of age-related changes in contextual memory. *Dissertation Abstracts International Section B: The Sciences and Engineering, 62 (6-B)*, 2970.

Troyer, A. K., Graves, R. E., & Cullum, C. M. (1994). Executive functioning as a mediator of the relationship between age and episodic memory in healthy aging. *Aging and Cognition, 1,* 45-53.

Tulving, E., Kapur, S., Craik, F.I., Moscovitch, M. & Houle, S. (1994). Hemispheric encoding/retrieval asymmetry in episodic memory: Positron emission tomography findings. *Proceedings of the National Academy of Sciences of the USA, 91,* 2016-2020.

Uttl, B. & Graf, P. (1997). Color-Word Stroop Test performance across the adult life span. *Journal of Clinical and Experimental Neuropsychology, 19,* 405-420.

Van der Linden, M., Bredart, S. & Beetren, A. (1994). Age-related differences in updating working memory. *The British Journal of Psychology, 85,* 145-52.

Van der Linden, M., Bruyer, R., Roland, J., & Schils, J.P. (1993). Proactive interference in patients with amnesia resulting from anterior communicating artery aneurysm. *Journal of Clinical and Experimental Neuropsychology, 15,* 525-536.

Van der Linden, M., Hupet, M., Feyereisen, P., Schelstraete, M.A., Bestgen, Y., Bruyer, R., Lories, G., Ahmadi, A.E. & Seron, X. (1999). Cognitive mediators of age related differences in language comprehension and verbal memory performance. *Aging, Neuropsychology and Cognition, 6,* 32-55.

Van Gorp, Wilfred, G., Satz, P. & Mitrushina, M. (1990). Neuropsychological processes associated with normal aging. *Developmental Neuropsychology, 6,* 279-290.

Verhaeghen, P., Marcoen, A. & Goossens, L. (1992). Improving memory performance in the aged through mnemonic training: A meta-analytic study. *Psychology and Aging, 7,* 242-251.

Wechsler, D. (1987). *WMS-R: Wechsler Memory Scale – Revised.* New York: Psychological Corporation.

West, R.L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin, 120,* 272-292.

West, R.L. (2000). Reply to Greenwood. *Journal of the International Neuropsychological Society, 6,* 705-726.

West, R.L. (2000). In defense of the frontal lobe hypothesis of cognitive aging. *Journal of the International Neuropsychological Society, 6,* 727-729.

Wheeler, M.A., Stuss, D.T., & Tulving, E. (1995). Frontal lobe damage produces episodic memory impairment. *Journal of the International Neuropsychological Society, 1,* 525-536.

Whelihan, W. M. & Lescher, E. L. (1985). Neuropsychological changes in frontal functions with aging. *Developmental Neuropsychology, 1,* 371-380.

Woodruff-Pak, D. D. (1997). *The neuropsychology of aging.* Oxford: Blackwell.

Yesavage, J. A., Brink, T. L, Rose, T. L. & Adey, M. (1986). The Geriatric Depression Rating Scale: Comparison with other self-report and psychiatric rating scales. In L. W. Poon (Ed.). *Handbook of Clinical Memory Assessment of Older Adults.* Washington, D. C.: American Psychological Association.

Yesavage, J. A., Brink, T. L., Rose, T. L., Lum, O., Huang V., Adey, M. B. & Leirer, V.O. (1983). Development and validation of a Geriatric Depression Rating Scale: A preliminary report. *Journal of Psychiatric Research, 17,* 37-49.

Zacks, R.T. & Hasher, L. (1994). Directed ignoring: Inhibitory regulation of working memory. In D. Dagenbach & T.H. Carr (Eds.), Inhibitory processes in attention, memory and *language* (pp. 241-264). San Diego, CA: Academic Press.

Zacks, R.T., Hasher, L. & Li, K.Z.H. (2000). Human Memory. In F.I.M. Craik & T.A. Salthouse (Eds.), *The Handbook of Aging and Cognition, 2nd ed.* (pp. 293-357). Mahwah, NJ: Lawrence Erlbaum Associates.