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THE ROLE OF EXECUTIVE FUNCTIONING AS A MEDIATOR
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Tara L. Victor

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THE ROLE OF EXECUTIVE FUNCTIONING AS A MEDIATOR OF AGE-RELATED DIFFERENCES IN FREE RECALL MEMORY PERFORMANCE

By

Tara L. Victor

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ABSTRACT

THE ROLE OF EXECUTIVE FUNCTIONING AS A MEDIATOR OF AGE-RELATED DIFFERENCES IN FREE RECALL MEMORY PERFORMANCE

By

Tara L. Victor

This thesis investigated the hypothesis that age-related free-recall memory decline is due to declines in executive function. The relative contributions of processing speed and working memory were also considered. It was hypothesized that executive function, processing speed and working memory would all mediate the relationship between age and free-recall memory performance. In addition, exploratory analyses concerning the relative contributions of different aspects of executive function (i.e. attention, response inhibition and set-shifting) to the relationship between age and memory were conducted. All variables were measured using standard neuropsychological tests with a sample of normal healthy elderly individuals. Hierarchical multiple regressions indicated that age (54-87) contributed only 8.8% to the variance in memory performance. Both executive function and processing speed when entered alone partially mediated the relationship between age and memory accounting for 52.3% and 73.9% of the variance, respectively. When entered together, they fully mediated the relationship accounting for 84.1% of the age-related variance. Working memory was not found to be related to free-recall memory performance. The difference aspects of executive function assessed in this study contributed similar amounts to the age-related variance. These results are discussed in light of their practical, theoretical and methodological implications and in the context of suggestions for future research.

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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. Being able to identify those cognitive elements that seem to characterize the mental status of elderly populations is very important to our understanding of this process and has major implications for the lives and psychological well-beings of these individuals.

One particular area of cognition that declines with age is memory (Craik, Anderson, Kerr, & Li, 1995). Much research has focused on age-related memory decline; however, there are many questions still left unanswered. The purpose of this study is to elucidate the mechanisms through which age exerts its effects on memory performance. A focus is placed on the mediating role of executive functioning processes, or 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).

However, any theoretical account of age-related memory decline must also take into consideration those processing resources that have consistently been found to mediate the age-memory relationship. More specifically, it will also be necessary to consider the influences of processing speed, the speed at which an individuals processes stimuli perceived, and working memory, the ability to simultaneously store and manipulate information (Baddeley, 1986, 1990; Lezak, 1995). Thus, a brief review of the research surrounding the roles of these theoretical constructs in the age-memory relationship is given below, followed by a more focused examination of evidence suggestive of executive function playing a significant role in age-related memory decline. However, it will first be necessary to review briefly the phenomena of age-related memory decline.

Age-Related Memory Decline

Some aspects of memory have consistently been found to decline with age. More specifically, age-related deficits have been found in at least some aspects of the three types of memory systems outlined by Shimamura (1990) 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 (!990) 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 construct of executive functioning.

The declarative system is 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. 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, Zonderman, Malamut, & Resnick, 1998). Similarly, a study by Paolo, Troester, & Ryan (1997) found a decline in performance with age on a measure of verbal learning and memory, the California Verbal Learning Test (CVLT).

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"; the relative strength of these associations is much smaller than for free recall

(Moscovitch & Winocur, 1995; Parkin & Walter, 1991; Rabinowitz, 1984). In sum, it is clear that an examination of the literature reveals the finding that different aspects of memory decline 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 variables potentially mediating the age-memory relationship. The question that is asked is this: Can age-related differences in memory be attributed to variables that intervene between age and memory and if so, to what extent? Or, stated in a statistical sense, to what degree do these potential mediating variables eliminate or attenuate the age-related variance in memory performance?

Potential Mediating Variables

Craik & 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. 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 attention focused on the 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 how quickly one can think and process information. 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 mediate a significant amount of the age-related variance in cognitive ability, generally (Park, Smith, Lautenschlager, Earles, Frieske, Zwahr, & Gaines 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 measures of memory performance (Hultsch, Hertzog, & Dixon, 1990; Luszcz, 1992; Salthouse, Kausler, & Saults, 1988).

It is clear that the research suggests processing speed seems to be a relevant mechanism through which age may exert 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 is a more general one as opposed to being linked to specific types of memory functions. Thus, this particular area of cognition is extremely important to research concerning memory decline with age. However, processing speed does not account for all the age-related variance found in memory performance. So this leads to another question: Are there other theoretical constructs involved in this relationship and what roles do they play? As cited above, 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 store and manipulate information simultaneously (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, 15; Fisk & Warr, 1996; Light & Anderson, 1985; Salthouse, 1988; Salthouse & Babcock, 1991). 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, 1992; 1993; Salthouse & Babcock, 1991; Van der Linden, Bredart, & Beerten, 1994). Thus, some researchers have postulated a two-factor resource model of variable mediation in the age-memory relationship that includes both perceptual speed and working memory (Park et al., 1996; Mayr & Kliegl, 1993; Nettelbeck & Rabbitt, 1992; Bryan & Luszcz, 1996). However, it seems that working memory may only be included in the mediational process for certain types of memory function. Specifically, Park et al. (1996) found that working memory mediated part of the relationship between 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 those requiring spatial memory abilities (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, in order to examine this role of working memory in the age-memory relationship the present study will use free recall performance as its measure of memory function.

Not only does there seem to be a resource contingency associated with working memory and its mediational influences, but there also 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 & Kliegl (1993) and Nettelbeck & Rabbitt (1992) found these two theoretical constructs to work as mediators together 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 secondary mediator through which speed, in part, exerted its effect on memory. This latter finding was also supported in a study by Salthouse & Babcock (1991) in which the potential influence of various working memory components on age-related deficits was 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.

Based on the literature examined thus far, it seems that both perceptual speed and working memory play very important roles in the decline of memory with age and should therefore be considered in any theoretical account of this phenomenon. It also seems that the influence of working memory may be one of secondary importance, but influencing memory performance directly, nonetheless.

Since processing speed and working memory are constructs that have been differentiated in the literature in terms of their mediating roles in the relationship between age and memory, the present study will control for these variables when examining the unique mediating influences of other aspects of executive functioning. Even though working memory has been considered to be a component of executive functioning, it has also already been consistently shown in previous research to mediate the age-memory relationship as described above; thus, its importance is known. What is not known, however, is the extent to which other aspects of executive functioning mediate the relationship between age and memory. Indeed, this particular theoretical construct as a whole has more recently been considered in terms of its potential to influence the age-memory relationship. A brief review of this research is provided below.

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. Those 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 goaldirected 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; Moscovitch & Winocur, 1992; Parkin, 1996; Troyer, Graves & Cullum, 1994; Woodruff-Pak, 1997). There is considerable evidence to support this hypothesis. 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 functioning and the frontal lobes of the brain has been supported in a number of studies demonstrating that executive functioning 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, Rao, Bernardin, Grafman, Yetkin, & Lobeck, 1994) and has been associated with the activation of the frontal lobes using PET technology (Berman, Ostrem, Randolph 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 (ST; 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, the tests of verbal fluency have also been thought of as measures of central executive abilities and thus a reflection of frontal functioning. Specific research associating verbal fluency performance with this particular area of the brain includes those studies reported by Moscovitch & Winocur (1995) in which deficits in the letter fluency task have been found in individuals with left orbitofrontal lesions. Verbal fluency test performance was also found by Crowe (1992) to decline when prefrontal pathology is present.

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 areas of the brain (Lezak, 1995). More recently, researchers have questioned whether those functions forming what is collectively referred to as the construct of executive function are actually localized in the frontal lobes of the brain (Parkin, 1998). These researchers argue that such cognitive functions may also be linked to the integrity of other neurological areas outside of the frontal system. 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 various cognitive abilities collectively known as 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 functioning and the frontal lobes of the brain is supported by much empirical research. The compelling arguments are those that attempt to make clear distinctions between the individual components of the construct. In order to address this issue in the present study, the correlations between the various measures of executive functioning will be examined. If the measures are not highly correlated with one another, suggesting the presence of independent influences of the different aspects of executive functioning, then the extent to which each aspect of executive functioning (as measured by the various tests used in this study) eliminates the variance in the age-memory relationship will be examined separately. In this way, different aspects of executive functioning, as measured by different neuropsychological tests, will be investigated individually. If, however, the measures of executive functioning do highly correlate with one another, suggesting the presence of one general construct, then the measures will be combined to form an overall composite score of the construct as a whole.

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 can be identified. First, there is an accumulation of evidence suggesting that executive functioning, as measured by a number of standard neuropsychological tests assessing this area of cognition, decreases with age. The second line of research linking this neuropsychological construct to age-related memory decline includes evidence suggesting that there is actual neurodegeneration of the frontal lobes of the brain during the aging process (Albert & Kaplan, 1980; Shimamura, 1990; West, 1996; Woodruff-Pak, 1997). 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. These three lines of research surrounding age-related declines in executive functioning are discussed below.

Age-related decline in executive function

The first of the three lines of research in support of the executive functioning hypothesis is the evidence suggesting that performance on standard measures of executive functioning declines with age. Based on their research findings, Albert & Kaplan (1980) developed what is known as the Frontal System Hypothesis, a hypothesis formed from their conclusion that older adults "do not develop adequate techniques for selectively attending to material unless a task is constructed in such as way that this necessity is minimized" (p.416). Their research found that when confronted with a task requiring the use of systematic and organized strategies for success, the elderly individual displays 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; 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). In addition, poorer performance (slower performance and increased errors) on the Stroop Test with advanced age have been consistently demonstrated (Boone, Miller, Lesser, Hill, & Elia, 1990; Houx, Jolles, & Vreeling, 1993; Spreen & Strauss, 1998) with age effects most prominent on the color-word interference trial (Cohn, Dustman, & Bradford, 1984; Diagneault, Braun, & Whitaker, 1992; Macleod, 1991). Whelihan & 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) and it is these types of errors that are the most strongly associated with frontal dysfunction (Heaton, 1981). Boone, Ghaffarian, Lesser, Hill-Gutierrez, & 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 & 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 for the demonstration of age-related decline executive functioning. For example, Haaland et al. (1987) did find 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 it is very clear that the majority of them do indicate such age-related impairment.

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). There are also 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). Other studies linking the normal aging process to deficits in frontal function include studies of brain anatomy (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. In addition, behavioral data also indicates a decline in frontal lobe functioning with age consistent with the neuroanatomical evidence (Albert & Kaplan, 1980; Whelihan & Lesher, 1985; Haaland, Vranes, Goodwin, & Gary, 1987). 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).

Combined with the abovementioned research 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.

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).

Explanations for the relationship between frontal function and memory performance have revolved around the idea that inadequate frontal function interferes with those processes necessary for successful acquisition 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 (dellaRocchetta, 1986; Craik & Lockhart, 1972; 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 is that older adults have difficulty using strategic and conscious processes for successfully accessing information needed 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 (Stuss, Kaplan, Benson, Weir, Chiuli, & Sarazin, 1982).

Summary and a Few Caveats

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. For example, Troyer et al., (1994) found the executive functioning 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. Thus, the results are inconclusive. The present study will examine the mediating effects of executive functioning along with those of processing speed and working memory on verbal free recall memory performance.

The rationale for focusing specifically on free recall performance is based on the results of the study by Parkin & Walter (1992) which indicated that an increase in non-contexually-based responses in a recognition memory task were related to poorer performance on the WCST. This suggests that contextually-based recognition memory performance decreases as frontal lobe functioning, as measured by tests of executive function, declines in older adults. This provides evidence for the role of executive functioning in recognition memory as it declines with age. It also suggests 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 frontal lobe functioning. Indeed, Moscovitch & 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 of partial mediation by the frontal lobes in recall in supported by the findings of many different studies (Moscovitch, 1989; Moscovitch & Umilta, 1990; Moscovitch & Umilta, 1991). A study by Wheeler, Stuss, & Tulving (1995) also supports this claim. These authors performed a meta-analysis of the effect of frontal lobe damage on episodic memory performance. Results indicated marked deficits in free recall performance. It was noted by Moscovitch & 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. 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. Thus, free recall is a memory task more likely to depend on elements of executive functioning than other types of memory tasks such as cued recall or recognition memory tasks, for example. Both of these use cues to aid recall and place less demands on cognition. In other words, a free-recall performance measure of memory will be sufficient for demonstrating the role of executive functioning in the age-memory relationship if, indeed, such a mediational effect does exist.

Postulates concerning the nature of the mediating role of executive function in this relationship certainly include the mediating effect of working memory. However, for the purposes of this paper, the constructs of executive functioning and working memory will be considered separately. There are many other components of executive function, such as attentional processes, mental flexibility in set-shifting, response inhibition, and verbal fluency that might also mediate the relationship between age and memory. The contributions of working memory and these other aspects of executive function are difficult to separate out, but the present study will attempt to examine the independent contributions of these constructs. Furthermore, 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 summary, the literature suggests that the aging process exerts its effects on memory performance, at least in part, through processing speed, working memory and executive functioning. This study will not only attempt to verify the existence of these mediating relationships, but will also attempt to make clear the extent to which executive functioning mediates the relationship between age and memory performance in comparison with the mediating effects of processing speed and working memory.

Hypotheses

Based on the research reviewed above, the specific hypotheses of the present study include the expectation of the following results:

(1) Confirmation of a decline in performance with age for all measures used including those assessing the variables of memory, executive function, processing speed, and working memory.

(2) Processing speed, working memory, and executive functioning will all mediate the relationship between age and memory performance. In other words, the relationship between age and memory will be reduced once processing speed, working memory and executive function are controlled.

(3) If the multiple measures used for executive functioning are not highly correlated with one another it may be that the different measures of executive functioning make different contributions to the age-related variance in memory performance. The extent to which each aspect of executive functioning (as measured by the various tests used in this study) eliminates the variance in this relationship will be examined in this case; however, hypotheses concerning this are exploratory in nature without strong a priori predictions.

METHOD

Participants

A total of 241 adults participated in this study ranging in age from 54-87 years (M = 68.97, SD = 7.8). All participants were home-dwelling community elderly individuals recruited through local newspaper advertisements and talks given to local community groups. Participant variables taken into consideration include number of years of education, 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), and 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 Beck Depression Inventory and/or 20 of higher on the Geriatric Depression Scale) were excluded from the sample. In addition, the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was used as a screening measure for cognitive functioning; only subjects scoring above the standard cutoff of 24 points were included in the final sample. This was to ensure that the sample examined was representative of the normal aging population. Given the exclusionary criteria used this study, the actual sample size used in the data analyses was 210. There were 118 females. Finally, each participant was offered the opportunity to participate in memory and attention training workshops as a result of participating in the study.

Procedure

Participants were individually administered a battery of tests aimed at assessing their mood and cognitive abilities in a session of 90-120 minutes. For the purposes of this study, however, only results from measures of executive functioning, processing speed, working memory, and verbal memory were analyzed and reported. All tests were of the paper-and-pencil type and the ordering of tests were randomly varied across participants. Other relevant background information was also gathered at the time of testing.

Measures

The measures used in this study include the following:

Screening Instruments

Beck Depression Inventory. (BDI; Beck& Beck, 1972): The BDI is a self-report measure consisting of 21 multiple-choice statements 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 interitem internal consistency estimate of .86 (Reynolds & Gould, 1981). Other researchers have reported a coefficient alpha for this measure of .88 (Steer et al., 1989). In addition, concurrent validity estimates between the BDI and 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 .75, .85 and .66, respectively.

Geriatric Depression Scale. (GDS; Yesavage, Brink, Rose, Lum, Huang, Adey & Leirer, 1983): The GDS consists of 30 yes/no self-administered questions for 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). It does, however, include somatic items which are thought to be more appropriate for older populations (Spreen & Strauss, 1998). The subject is required to read each statement and answer by circling the yes/no response which most accurately reflects their experience. 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).

In terms of reliability, the item-total correlations of the GDS range from .32-.83, the split-half correlation was .94 and the internal consistency was also found to be .94 (Koenig et al., 1988). The GDS correlates 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 DMS-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 minor factors were revealed: one of worry, dread and obsessive thought and the other one of apathy and withdrawal (Parmelee, Lawton, & Katz, 1989). Criterion validity has been measured against the Research Diagnostic Criteria and found to be .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. 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. Test-retest reliability for this test over a 2 year period was .38. 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 convergent validity 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).

Processing Speed (PS)

One measure of processing speed was used in this study. The Symbol Digit Modalities Test (SDMT; Smith, 1991) is a timed test comprised of both written and verbal components. In the written portion of the test the subject is asked to write in numbers in empty boxes that are placed below that of boxes with various nonsense syllables. The correct number to be recorded is determined by the subject's use of a key presented at the top of the page. The key pairs each of the nine nonsense geometrical figures with the numbers one through nine. In the oral portion of the test, the correct numbers are recorded by the examiner. 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 was assessed through use of the WAIS-R (Wechsler, 1981) Backward Digit Span Subtest (DSpB). This test 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).

Executive Function (EF)

EF was assessed by three different measures including 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 at the words in the reading trial. Finally, the second naming trial requires the naming of color when names of colors are printed in a color that is different from the actual word itself. This second naming trial is the "interference" condition.

Scores on this test indicate the decrease in color-naming which is called the "color-word interference effect." The Stroop effect is the phenomenon that occurs with increasing errors and decreasing number 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 including a verbal fluency test ($r = .58$) and a version of the Tower of London ($r = .65$) (Spreen & Strauss, 1998). Reliability for this test is reported to be "satisfactory" by Lezak (1995). More specific test-retest reliabilities were reported by Spreen & Strauss (1998) to be .90, .83, and .91 for the three portions of the Stroop.

Wisconsin Card Sorting Test. (WCST; Heaton, 1981): The WCST is a test that requires the participant to sort up to 128 consecutive cards, on which are printed one to four symbols 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 by which to sort the cards and this changes each time the participant sorts 10 cards correctly. This change is not conveyed to the participant; it must be deduced from examiner feedback and 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.

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 "the ability to form abstract concepts, to shift and maintain set, and utilize feedback"(Spreen & Strauss, 1998). It has also been described as a measure of hypothesis formation and set-shifting (Moscovitch & Winocur, 1995) and 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). Validity evidence for this test as a measure of frontal lobe functioning includes research findings that individuals with prefrontal lesions tend to display perseverative responses on this test (Milner, 1964; Heaton, 1981; Anderson, Jones, Tranel, Tranel, & Damasio, 1990). In addition, neuro-imaging technique research has also providing 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 normal old adults (Raz, Gunning, Head, Briggs, Dupuis, McQuain, Loken, Thornton, & Ackers, 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, Anderson, Alliger, Cohen, Swayze, & O'Leary, 1993). Finally, PET findings also indicate that performance on the

WCST is associated with frontal lobe functioning (Berman, Ostrem, Randolph, 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 to 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 was scored as the time required to complete each trial, and the difference in time between trials B and A was calculated and used as a measure of performance on this test. This difference score reflects the time of cognitive processing (B) subtracted from 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).

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 substantive validity evidence suggesting that this test is also a measure of frontal lobe functioning (Reitan, 1958, 6; Picton et al., 1986). Reliability of the difference score is reported to be .71 (Lezak, 1995).

Free-recall Memory Performance

Performance in free recall memory performance was assessed by the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987). 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 period of free-recall. Each list consists of four items that 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 with the subject's objective being that of identifying those items on Monday's list. There are no time limits on any of the memory tasks undertaken with this test.

In the free recall portion of the CVLT participants receive a list of 16 different words. Within this list existed four categories of words including fruits, clothing, tools and spices/herbs. The words are presented verbally one second per word. After all words are read by the experimenter, the participants are asked to recall the words they just heard in any order. Recall occurs after each list is presented. 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. Therefore, a composite score that combined these three scores was used as an overall indicator of 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.

The authors of this test report split-half reliability coefficients ranging from .77-

.86. Analyses on this tests's normative sample also revealed a coefficient alpha of .74 (Delis, Freeland, Kramer & Kaplan, 1988). The correlations between the CVLT and other tests purporting to measure the intended construct are said to be modest (Lezak, 1995).

RESULTS

Descriptive Statistics

Means and standard deviations of age, years of education, BDI, GDS and MMSE scores for this sample are displayed in Table 1.

Means, standard deviations and correlations among the study variables and age appear in Table 2. As predicted in hypothesis #1, age was correlated negatively, but modestly, with free-recall memory performance ($r = -.30$ and $p < .01$). Age correlated with the executive function measures, such that increasing age was associated with poorer performance (Trailmaking Test (TMT) $r = .30$ and $p < .01$; Wisconsin Card Sorting Test (WCST) $r = .30$ and $p < .01$), with the exception of the Stroop Test interference score which was not associated with age. Therefore, no further analyses were conducted with this particular test of executive functioning. As a result, the operationalization of executive function was limited to the TMT and the WCST. Age was also related with the speed of processing measure, the Symbol Digit Substitution Test (SDMT) ($r = -.46$ and $p < .01$) such that increasing age was associated with slower performance. Increasing age was also associated with lower working memory performance as measured by the Backwards Digit Span of the WAIS-R (DSpB) ($r = -.21$ and $p < .01$).

Of the executive function measures, the TMT ($r = -.20$ and $p < .01$) and the WCST ($r = -.22$ and $p < .01$) correlated with free recall, such that higher performance was associated with better recall. The measure of processing speed, SDMT, correlated most strongly with recall with faster processing related to better recall ($r = .36$ and $p < .01$). Finally, the measure of working memory was not found to be associated with recall performance to any significant degree and was therefore not included in subsequent analyses.

Composite Scores

Based on the correlations between various measures, composite scores were formed to simplify analyses and to avoid overmodelling the data. First, as displayed in Table 3, correlations between the three scores of free-recall performance as assessed by the CVLT were positive and significant. Therefore, a composite score that combined the average free-recall of the first five trials, short-delay and long-delay free-recall of this measure was used as an overall indicator of memory performance by converting each of these scores to z-scores and summing them resulting in a single composite measure of free-recall memory. This composite score was used in all subsequent analyses. Second, as can be seen in Table 2, the correlation between the remaining two tests of executive functioning (TMT and WCST) was positive and significant ($r = .23$ and $p < .01$) and so these scores were also converted to z-scores and summed to form a single composite measure of executive functioning. As seen in Table 2, this composite score (EXECUTIVE) correlated with age such that increasing age was associated with poorer performance ($r = .39$ and $p < .01$). The EXECUTIVE composite also correlated with free-recall memory such that better performance on the executive tasks was associated with better performance on the memory task ($r = -.27$ and $p < .01$).

Tests for Linearity

Prior to conducting the regression analyses, the relationship between age and all cognitive measures was examined to determine whether or not there were any non-linear components. The cognitive measures were regressed on age. Subsequent addition of a quadratic function of age to the regression models did not produce a significant increase in R^2. Thus, none of the relationships deviated from linearity which simplified all later analyses.

Hierarchical Regression Analyses

In order to elucidate the mechanisms underlying memory function and age-related differences in memory, hierarchical multiple regression analyses were used. The dependent variable for the regressions was the free-recall memory composite score. Hypothesis #2 involved the prediction that measures of executive function, processing speed and working memory would account for the age-related variance in free-recall performance. As stated above, working memory was not related to free-recall. In other words, the prediction that working memory would mediate the relationship between age and memory was not supported. Thus, this variable was not included in the regression analyses.

Hypothesis #3 involved the exploratory analysis of the relative contributions of the difference aspects of executive function assessed in the study to the relationship between age and memory. As stated above, the Stroop was not found to be associated with age and was therefore not included in further analyses. However, performance on both the TMT and the WCST was found to be related to age and to free-recall memory in the expected directions and so the relative contributions of the aspects of executive function measured by these tasks to age-related memory decline were examined. TMT scores were included as a primary measure of attentional processes and the WCST number of perseverative errors was included in the analyses as a primary measure of set-shifting; both are important cognitive abilities lying under the rubric of executive function.

The results of the multiple regression analyses appear in Table 4. Models 1-4 address Hypothesis #2. Model 1 shows the amount of variance in free-recall memory performance predicted by age alone for this sample. Models 2 and 3 assess the age-related variance in free-recall memory after controlling for executive function and processing speed, respectively. Model 4 assesses the age-related variance in free-recall memory after controlling for both processing speed and executive function together. It also assesses the relationship between executive functioning and memory once processing speed has been taken into account. By comparing the relative effects of age in Models 1 with Model 2, one can assess the amount of age-related free-recall variance accounted for by a decline in executive function. By comparing the relative effects of age in Models 1 with Model 3, one can assess the amount of age-related free-recall variance accounted for by a decline in processing speed. And finally, by comparing the relative effects of age in Models 1 with Model 4, one can assess the amount of age-related free-recall variance accounted for by processing speed and executive function together.

Models 5 and 6 address Hypothesis #3. More specifically, models 5 and 6 assess the age-related variance in free-recall after controlling for attention and set-shifting, respectively. The comparison of these two models allows one to examine the relative contributions of these two aspects of executive function to age-related memory decline.

These results indicate that there was at least a partial reduction in the age-related variance in memory performance in each case where the potential mediating variables were controlled. Thus, each of these variables accounted for, or explained, part of that age-related variance. The actual percentage of age-related variance (%ARV) accounted for by mediating variables also appears in the Table 4. This index is calculated by computing the difference between the age-related variance in memory before and after mediating variables had been entered, divided by the amount of age-related variance before mediators had been entered, multipled by 100.

Model 1 shows that age predicted 8.8% of the variance in recall when entered alone; this represents 100% of the age-related variance in free recall performance. Model 2 shows that executive function predicted 7.1% of the variance in free recall which represents 52.3% of the age-related variance (% AVR = (.088 - .042) / .088). However, after executive function had been entered, age continued to accounted for a significant part of the variance in free recall (4.2%), and so executive function was only a partial mediator in the relationship between age and free recall. Model 3 shows that processing speed contributed 12.6% of the variance in free recall which represents 73.9% of the age-related variance. However, after processing speed had been entered, age continued to account for a significant amount of the variance in free recall (2.3%), and so processing speed was only a partial mediator in the relationship between age and free recall. Model 4 shows that when entered together, executive function and processing speed predicted 14.6% of the variance in free recall and, after these variables had been entered, age accounted for a nonsignificant 1.4%, which represents 84.1% of the age-related variance. Thus, these variables when entered together, completely mediated the relationship between age and free recall. Model 4 also shows that executive function continues to be a significant predictor of memory performance even when processing speed has been controlled. Model 5 shows that attention predicted a significant 4% of the variance in free recall which represents 31.8% of the age-related variance. Model 6 shows that set-shifting predicted a significant 4.8% of the variance in free recall which represents 35.2% of the age-related variance.

DISCUSSION

Hypothesis #1 of this study involved the prediction that there would be significant age-related declines in performance on measures of executive functioning, processing speed, working memory and free-recall memory. This hypothesis was supported. One exception was the Stroop Color and Word Test (Stroop), one of the executive function measures. This is surprising as there exists a vast amount of literature indicating a decline in performance on this test with increasing age (Boone et al., 1990; Cohn et al., 1984; Diagneault et al., 1992; Houx et al., 1993; Macleod, 1991; Spreen & Strauss, 1991; Whelihan & Lesher, 1985). Albeit less consistently, however, others have also failed to find a relationship between Stroop performance and age (Bryan, 1998). This may be am important finding. It may be that in highly competent older adults there is no significant decline in Stroop performance, or prior decline in the abilities assessed in this task as a function of age have already taken place and are therefore not picked up in the context of a nonlongitudinal design.

Hypothesis #2 predicted that processing speed, working memory, and executive functioning would all mediate the relationship between age and memory performance. This hypothesis was only partially supported. More specifically, working memory was not found to be associated with free-recall memory performance and, as a result, was not included in subsequent analyses. In light of previous research implicating working memory as an important mediator in the relationship between age and memory performance (Bryan & Luszcz, 1996; Campbell & Charness, 1990; Foos, 1989; Mayr & Kliegl, 1993; Nettelbeck & Rabbitt, 1992; Park et al., 1996; Salthouse, 1992; 1993; Salthouse & Babcock, 1991; Van der Linden et al., 1994) and in light of the vast amount of literature indicating a decline in performance on the Stroop with increasing age (Boone et al., 1990; Cohn et al., 1984; Diagneault et al., 1992; Houx et al., 1993; Macleod, 1991; Spreen & Strauss, 1991; Whelihan & Lesher, 1985), the most likely explanation for not finding the existence of expected relationships with this sample may be related to the attenuation of correlations in this study due to small variances in performance for the measures used in this study. In addition, the reliability of the measures used, though satisfactory, it certainly not perfect. Imperfect reliability most likely also attenuated the correlations in this study. These methodological limitations are discussed and further elaborated upon in a later section of this report.

Although support for this hypothesis was not found with regard to the construct of working memory, both processing speed and executive function were found to account for some of the age-related variance in free recall. However, after controlling for these variables, age continued to significantly predict free recall; thus, executive function and processing speed were only partial mediators of the relationship between age and memory when entered into the regressions alone.

In addition, the results suggest that processing speed contributes more to age-related free recall performance (73.9%) than executive function (52.3%). This finding is not entirely surprising as research has been particularly consistent in demonstrating a decline in processing speed with age (Cerella, 1990; Fisk & Warr, 1996; Hartley, 1986, 1993; Hultsch et al., 1990; Kail & Salthouse, 1994; Salthouse, 1985, 1992; Schaie, 1989, 1994; Van Gorp, Wilfred, Satz, & Mitrushina, 1990) and in demonstrating the mediating role of processing speed in the relationship between age and various aspects of cognitive functioning (Lindenberger et al., 1993; Park et al., 1996; Salthouse, 1993, 1994;

Salthouse & Babcock, 1991). In fact, Salthouse (1980, 1985, 1996) has argued that memory performance, in particular, is negatively affected by age and that this negative relationship is due, in part, to a decline in the speed of information processing. Indeed, 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 measures of memory performance (Hultsch et al., 1990; Luszcz, 1992; Salthouse et al., 1988). Explanations for this relationship are compelling and include the argument that the rate at which to-be-remembered items can be rehearsed or repetitively cycled is decreased by a decline in processing speed with age and this, in turn, accounts for deficits observed in memory performance (Baddeley, 1986; Salthouse,1980).

The results of the regression analyses also indicate that processing speed and executive function, together, significantly reduce the relationship between age and memory, accounting for 84.1% of the age-related variance in free recall. In other words, age was no longer a significant predictor of free recall performance when both of these variables were taken into consideration. Thus, the importance of both of these variables in age-related memory decline is highlighted in this study. This finding lends a large amount of support to the executive functioning hypothesis. Also leading support to this hypothesis is the fact that executive function continued to be a significant predictor of free recall performance when processing speed had been controlled. Thus, one can say that the role of executive function in memory performance is significant and above and beyond that of processing speed in this study.

Explanations for the role of executive functioning in the relationship between age and memory performance include the idea that inadequate frontal function interferes with those processes necessary for successful acquisition and retrieval of information. As reviewed earlier in this report, 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 (dellaRocchetta, 1986; Craik & Lockhart, 1972; 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 is that older adults have difficulty using strategic and conscious processes for successfully accessing information needed 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 (Stuss et al., 1982).

Hypothesis #3 stated that if the multiple measures used for executive functioning were not highly correlated with one another their contributions to age-related free-recall performance would be examined separately and that the nature of these examinations would be exploratory in nature. As noted above, performance on the Stroop Test was not included in the mediational analyses since scores on this test were not found to be associated with age. However, the two remaining tests of executive functioning (Trailmaking Test and Wisconsin Card Sorting Test) were found to be associated with age and were included in all analyses. The correlation between scores on these two tests was found to be positive and significant; however, the correlation was modest. Consequently, the two aspects of executive functioning that these two tests purport to measure (attention and set-shifting) were treated as separate constructs in models 5 and 6 of the regression analyses. It was thought that this type of analysis (examining each of the two aspects of executive functioning separately) would provide a more detailed, precise picture of the role executive function plays as a mediator in the relationship between age and memory as compared to examining the construct as a single unity (Parkin, 1998). The results indicated that both attention and set-shifting contributed similar amounts to free-recall performance and both accounted for similar amounts of the age-related variance in free-recall performance.

It should be addressed that age contributed only 8.8% to the overall variance in memory performance in this particular sample of older adults. This finding is surprising in light of a long history of past research consistently demonstrating a decline of memory with age (e.g. Burke & Light, 1981; Golski et al., 1998; Moscovitch & Winocur, 1995; Paolo et al., 1997; Shimamura, 1990). 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 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 may involved in age-related cognitive decline. In addition, however, this could also be an underestimate of the variance in memory 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 becomes quite clear that difficulty arises in interpretation of the findings because of certain methodological limitations. Below is a discussion of the major limitations identified in the present investigation.

Measurement Issues

First, 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 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 is different for different people working within this area of research and this makes comparison between studies and interpreting data very difficult. This questions 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.

Indeed, 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. In other words, 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 can be postulated to 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 that interfere with the accurate assessment of her performance. 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 reliability data available (Spreen & Strauss, 1998).

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. It would then be possible to combine scores on the related measures to form composite scores that can be assumed to be more accurate representations of the constructs of interest. This is a procedure endorsed by Salthouse & Babcock (1991). This study used this approach with regard to free-recall memory.

However, it would have been ideal to include multiple measures of all constructs examined in this study. The use of factor analytic techniques to provide further construct validity evidence for chosen measures would also have been ideal.

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 and/or exhibited impaired performance on a dementia screener. 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 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 15.85. This is a relatively high mean level of education. 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. 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 because of a restriction of range in performance.

This discussion highlights the fact that a younger comparison group was not included in this study. Including younger groups for comparison purposes would have increased the range of variation in performance. The comparison of extreme age groups as opposed to the exploring questions of interest in a continuous age range sample would be more likely to pick up on and emphasize age-related variance in cognitive performance. 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 the 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 co-occurring 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 the variables, 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 hierarchical regression as was done in the present study; however, a more sophisticated and informative approach for elucidating the mechanisms through which the relationships exist may lie in the use of statistical techniques such as structural equation modeling. The utility of this particular type of data analysis in this area of research is provided below along with other recommendations for future research.

Future Research

As briefly mentioned above, there are some noteworthy comments to be made concerning issues related to data analysis and measurement of constructs for future research in this area. More specifically, a developing trend in this area of research has been the use of statistical procedures such as structural equation modeling. There are many strengths associated with using this particular approach. First, it permits the simultaneous evaluation of competing theoretical views within a single analytical paradigm. Second, it provides a more easily understandable account of the relative contributions of different mechanisms to the behavior of interest, in this case the decline of memory with age. Third, it allows you to control for measurement error in your study. Finally, the use of structural equation modeling allows you to examine a theoretical construct at different levels of analysis. For example, it makes it easy to look at the contributions of the variables of interest on recall and recognition separately. However, it also allows for analysis of a more general memory construct combining all memory tasks.

Another issue related to data analysis and measurement worth noting is the importance of using factor analytic techniques in this area of research. Future research should strive to achieve the most accurate 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.

In addition, future research would likely benefit from the inclusion of a younger comparison group to increase the variation in performance assessed and, in turn, highlight age-related differences in cognition, including differences in other types of memory not accounted for in this study. As stated in a previous section of this report, it is likely that executive function processes, in particular, will play different roles with regards to recognition or cued memory tasks as compared to free-recall tasks. The potential mediating roles these variables play in other types of memory performance (i.e. prospective memory) is also important and warrants further investigation. In addition, this study found the two aspects of executive functioning assessed to account for similar amounts of the age-related variance in memory performance; however, the roles of other aspects of executive functioning are still unknown and should thus be examined in future research in this area. Similarly, the roles of other relevant cognitive variables as potential mediators in this relationship should be examined. Together, processing speed and executive function accounted for approximately 84% of the age-related variance in memory performance. Clearly, there is variance left unexplained. Investigation of other potentially relevant factors is certainly warranted.

Summary and Conclusions

To summarize, it appears that executive function and processing speed only partially mediate age differences in free-recall when considered alone. However, when considered together, these variables completely mediate the relationship. These findings highlight the importance of both processing speed and executive function in the relationship between age and memory. It was also found that executive function continued to be a significant predictor of age-related variance in memory performance once processing speed was controlled. This lends a large amount of support to the executive function hypothesis of cognitive aging and, again, highlights this construct's importance in the relationship between age and memory. This study also found that two specific aspects of executive function, attention and set-shifting, made similar contributions to the relationship between age and memory performance; however, the relative contributions of other aspects of executive function are still unknown. It is advised that future research continue with attempts to further elucidate the mechanisms through which these relationships exist.

APPENDIX

APPENDIX

Table 1

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

Participant Variable	N	Mean (SD)
Age (years)	210	68.97 (7.8)
Years of Education (years)	210	15.85 (3.02)
Estimated VIQ*	210	117.74 (14.0)
BDI total score	210	6.32 (4.8)
GDS total score	210	5.86 (5.0)
MMSE total score	210	28.39 (1.5)

Note. The equation used to compute the estimated VIQ = 118.2 - .89 (AMNART errors) + .64 (Years of Education); (Grober & Sliwinski, 1991).

Table 2

Means, standard deviations, and correlations among all study variables and age.

Constructs (Measures)	Mean (SD)	Age	Working Memory	Processing Speed	EF: Attention	EF: Response Inhibition	EF: Set-Shifting	EF: Composite	Free-recall Memory
Working Memory (DSpB)	6.52 (2.2)	-21**	1.00						
Processing Speed (DSMT)	52.36 (12.5)	-46**	.29**	1.00					
EF: Attention (TMT)	55.86 (33.1)	.30**	-.29**	-.35**	1.00				
EF: Response Inhibition (Stroop)	4.80 (9.2)	.03	.07	.09	-.21**	1.00			
EF: Set-Shifting (WCST)	15.89 (12.5)	.30**	-.14	-.27**	.23**	-.20**	1.00		
EF: Composite		.39**	-.26**	-.40**	.79**	-.26**	.79**	1.00	
Free-Recall Memory (CVLT)		-.30**	.13	.36**	-.20**	.17*	-.22**	-.27**	1.00

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

For EF: Attention, EF: Set-Shifting, and the EF: Composite positive correlations indicate a decline in performance on these tests with increasing age.

Sample sizes ranged from 202-210.

EF = Executive function.

The EF Composite and Free-Recall Memory scores were based on the sum of standardized individual test scores. No mean or standard deviation for these scores are listed as a result.

Table 3

Correlations between the three free-recall scores as assessed by the CVLT.

Score	Five Trial Average	Short-Delay	Long-Delay
Average Five Trials	1.00		
Short-Delay	.83**	1.00	
Long-Delay	.84**	.88**	1.00

Note. ** p value <.01.

Table 4

Hierarchical multiple regression analyses predicting free-recall memory performance from age, executive function, processing speed, attention and set-shifting.

Model	Step	Predictors	Beta	R^2	R^2 Change	%ARV
1	1	Age	-.296	.088	.088**	100.0
2	1	Executive Function	-.267	.071	-----	
	2	Age	-.225	.113	.042**	52.3
3	1	Processing Speed	.355	.126	-----	
	2	Age	-.172	.149	.023*	73.9
4	1	Processing Speed	.355	.126	-----	
	2	Executive Function	-.156	.146	.020*	
	3	Age	-.140	.161	.014	84.1
5	1	Attention	-.199	.040	-----	
	2	Age	-.259	.100	.060**	31.8
6	1	Set-Shifting	-.218	.048	-----	
	2	Age	-.250	.104	.057**	35.2

Note. * $p < .05$, ** $p < .01$
ARV = age-related variance accounted for
Sample sizes ranged from 199 to 206.

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