This is to certify that the

thesis entitled

The Role of Inhibition in Working Memory Performance
Associated with Age

presented by

Carol Catherine Persad

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Psychology

Rose T. Zacks
Major professor

Date Aug 23, 2000

THE ROLE OF INHIBITION IN WORKING MEMORY PERFORMANCE ASSOCIATED WITH AGE

By

Carol Catherine Persad

A DISSERTATION

Submitted to

Michigan State University

In partial fulfillment of the requirements

For the degree of

DOCTOR OF PHILOSOPHY

DEPARTMENT OF PSYCHOLOGY

2000

ABSTRACT

THE ROLE OF INHIBITION IN WORKING MEMORY PERFORMANCE ASSOCIATED WITH AGE

By

Carol Catherine Persad

The current investigation addressed the view that inefficient inhibitory processes account for some of the age-related declines in performance on measures of working memory (WM). Two studies were designed that incorporated WM measures chosen from the neuroimaging literature. Study 1 examined age differences between young (18-29) a young-old (60-74) and an old-old group (75+) on versions of the n-back and item recognition tasks (Jonides et al. 1998; Smith & Jonides, 1997). The tasks included critical trials for which it was presumed that inhibitory processes were particularly important for successful performance. According to the inhibitory deficit view, older participants should show particular difficulty on these trials. Results generally supported this hypothesis. Not only did the older adults have more difficulty than the young adults on these tasks overall, they also showed relatively more difficulty on those trials that were theorized to rely more on the integrity of inhibitory processes for successful performance. No differences were found between the two older groups. Study 1 also addressed the suggestion of some researchers that inhibition is partly subserved by the prefrontal cortex (PFC). In particular, performance on the WCST, often described as a putative measure of frontal lobe functioning was correlated with performance in the 2-back version of the n-back task, lending some support for the relationship between the PFC and inhibitory

mechanisms. Study 2 investigated performance on the item recognition task in relation to age-related information processing speed changes as assessed by two perceptual speed measures (Salthouse, 1996). Additionally, in an attempt to vary the amount of interference across trials, Study 2 also included a comparison between categorized and unrelated word lists. Because of prior strong associative bonds between category members, it was expected that the categorized list condition would particularly impair performance in the older adults due to inefficient inhibitory mechanisms. It was also hypothesized that although age-related changes in processing speed would account for some of the differences in this working memory task, (a) it would not account for all of age-related variance, and (b) it would account for less of the variance in the categorized list condition than the unrelated condition, presumably because inhibition was also important to performance, particularly in the categorized condition. The category manipulation did not achieve the desired results; contrary to expectations, performance was better in the categorized list condition compared to the unrelated condition. Hierarchical regression analysis indicated that perceptual speed accounted for much of the age-related variance in the item recognition task. Nonetheless, the interpretation of such findings as necessarily supporting a processing speed explanation of age-related changes in cognition is called into question by recent findings indicating that age differences on perceptual speed measures are partly a reflection of differences in susceptibility to interference effects from visual distraction. This outcome suggests that the fundamental factor in regression analysis may be inhibitory efficiency rather than processing speed. Further studies are needed to evaluate the relative role of processing speed and inhibition to age changes in performance on WM tasks.

ACKNOWLEDGMENTS

First and foremost I would like to thank my family for their considerable love, support and patience. I would like to thank Rose Zacks, my mentor, for her knowledge, guidance and support, as well as the other members of my dissertation committee for their helpful comments and suggestions. I would like to thank Ruth Dryden for her invaluable help in subject recruitment and data collection and Tim Salthouse for providing me with the perceptual speed measures. Thanks also go to Karin Butler and Carrick Williams for their assistance in designing the computer programs.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Age-related deficits have been found on a variety of tasks designed to measure working memory (Salthouse, 1994; Verhaegen & Salthouse, 1997). Different theories have been proposed to account for these age differences, including a reduced ability to use self-initiated processing due to reduced working memory resources (Craik & Anderson, 1999; Craik & Byrd, 1982), a generalized slowing of information processing speed (Salthouse, 1996), and a reduction in the efficiency of inhibitory functioning (Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999; Zacks & Hasher, 1994; see Light, 1991 for a review). Although each theory has garnered support, the current investigation focused on the inhibition theory of aging.

It has been proposed that inhibition, together with excitation, is a necessary component of attentional processes for successful and efficient execution of a variety of tasks and behaviors including those that rely on working memory (e.g. Bjork, 1989; Neumann & DeSchepper, 1992; Tipper, 1985; Tipper, Weaver, & Houghton, 1994). To this end, inhibition is thought to serve three main purposes in support of efficient working memory (Hasher et al., 1999). First, by preventing extraneous, distracting information from entering working memory, inhibition can allow for more efficient processing of target or goal-relevant information. The distracting information can be from the external environment as well as from internal thoughts and associations. Along with extraneous information, previously relevant information can also cause interference if it remains activated in working memory beyond its applicability to the task at hand. In a constantly changing environment, task demands frequently change or new goals are chosen, making stimuli that were originally the focus of processing no longer relevant to the end goal. Thus, inhibitory processes, by suppressing or deleting old information from working memory, allow for a re-focusing on new information and aid in reducing possible interference effects that could otherwise occur given simultaneous activation of irrelevant stimuli. Lastly, inhibitory processes can prevent the occurrence of prepotent responses to stimuli/situations that may not be appropriate to the current context. When inhibitory processes become inefficient, irrelevant and potentially distracting information enters or remains in working memory, making it more difficult to carry out other cognitive processes effectively, presumably due to interference effects and response competition.

Hasher and Zacks (Hasher & Zacks, 1988; Hasher et al., 1999; Zacks & Hasher, 1994) have proposed that inefficient inhibitory processes are one mechanism that accounts in part for a variety of age-related cognitive deficits. If inhibitory functioning is less effective in old adults, in comparison to young adults, irrelevant and potentially interfering information can enter or remain in working memory, making it more difficult to efficiently execute the necessary processing for a given task. Because working memory has been implicated in a wide variety of cognitive tasks, deficient inhibitory functioning can potentially affect older adults' performance in many cognitive domains.

There is considerable support for the inhibition theory of aging, although there are notable exceptions. Research findings have shown that inefficient inhibitory processes affect performance on a variety of tasks in old adults. These include language and reading comprehension skills (Connelly, Hasher & Zacks, 1991; Hamm & Hasher, 1992; Hartman & Hasher, 1991; See & Ryan, 1995), selective attention processes as measured by negative priming procedures (Hasher, Stoltzfus, Zacks & Rypma, 1991; May, Kane, &

Hasher, 1995), the ability to inhibit a prepotent response as measured by performance on the Stroop task (Dempster, 1992) and the antisaccade task (Butler, Zacks, & Henderson, 1999), and the ability to learn and retrieve multiple associations to various facts (Gerard, Zacks, Hasher, & Radvansky, 1991). Older adults do not always exhibit impaired inhibition, however. For example, although there is considerable evidence demonstrating reduced negative priming in older adults, there are also an equal number of studies that have not found these age differences, particularly under varying task conditions (Langley, Overmier, Knopman, & Prod'Homme, 1998; Schooler, Neumann, Caplan, & Roberts, 1997; Sullivan & Faust, 1993). In addition, older adults have been found to do as well as younger adults on a variant of the Stroop task (Li & Bosman, 1996), and on tasks requiring the individual to ignore distracting information based on spatial cues (Carlson, Hasher, Connelly & Zacks, 1995; Connelly & Hasher, 1993). These exceptions have led some researchers to suggest that there may be multiple inhibitory mechanisms, only some of which are age sensitive (Carlson, Hasher, Connelly & Zacks, 1995; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Li & Bosman, 1996).

Older adults do appear to have particular difficulty suppressing or deleting information from working memory that is no longer appropriate for task completion. Certain types of errors made by older adults provide indirect evidence of this difficulty. For instance, older adults have greater difficulty on tasks of cognitive flexibility that require switching from one strategy or behavior to another. On these tasks, once a response set has been established, older adults experience difficulty altering their behavior when task conditions change. The result is an increase in perseverative responses (Cronin-Golomb, 1990; Lezak, 1995; Veroff, 1980). The combination of difficulty in shifting set and perseveration is consistent with the theory of a reduced suppression mechanism. Older adults also exhibit more intrusions of material from earlier trials during tests of free recall, a finding that is also suggestive of a deficient suppression mechanism (Koriat, Ben-Zur, & Sheffer, 1988; Larrabee, Trahan, Curtiss, & Levin, 1988). In addition a recent study has demonstrated that performance on traditional working memory span measures, generally used as an indication of an individual's capacity of working memory, is significantly influenced by a build up of proactive interference (May, Hasher & Kane, 1999), especially for older adults.

Other studies have tried to investigate the suppression mechanism more directly. For example, reading tasks that make use of garden-path sentences (Hartman & Hasher, 1991) and passages (Hamm & Hasher, 1992) provide results consistent with the view that efficiency of inhibitory processes declines with age. The materials are called "garden path" texts because they are designed to initially mislead the reader to arrive at one interpretation, which later turns out to be incorrect. Although both young and old adults do arrive at and maintain the correct interpretation, unlike young adults, the old adults also maintain the incorrect interpretation. These findings have been demonstrated both on indirect tests (sentence completion tests) and direct tests of memory (speeded judgment tasks).

Zacks, Radvansky and Hasher (1996) used a directed forgetting paradigm to investigate suppression ability in older adults. In the typical directed forgetting procedure a list of words is presented to the participant. After each word or after a block of words has been presented, a cue is given that tells the subject whether the word(s) are to be remembered or forgotten. Because the cues are presented after the word has been presented and because the subject does not know until then whether the particular item is to be remembered or forgotten, it is assumed that the person must attend to each word and process it. Once the entire list has been presented, participants are asked to recall all of the to-be remembered words (TBR). The assumption is that once the forget cue is presented, an individual must delete or suppress those words in working memory so that these items (the "to-be-forgotten words," or TBF) will not intrude or interfere with recall of the TBR words. On such tasks, not only do young adults have little difficulty recalling TBR words and give few intrusions of TBF words (Bjork, 1989; Geiselman & Bagheri, 1985), their recall of the TBR words is equivalent to trials in which the TBR words were presented alone. Performance levels are as if the TBF words were never presented supporting the view that the young adults successfully suppress the TBF items to the extent that these items do not interfere with recall of the TBR words. In contrast, old adults exhibited higher intrusion rates of TBF words at recall in comparison to trials in which the TBR words are presented alone (Zacks, et al., 1996). The older adults appeared to have problems suppressing the irrelevant information leading to reduced performance. These results suggest that the inability to suppress TBF words can affect recall performance in two ways; by increasing the difficulty in correctly recalling the target material and by increasing the number of intrusions of the irrelevant material.

Taken together, these results support the view that older individuals have difficulty suppressing material that is no longer relevant in working memory. As a result, interference can occur with the presence of this distracting material, leading to reduced performance at both the information processing/encoding stages (as seen in language comprehension) as well as at the time of retrieval (for example, lowered performance on directed forgetting tasks). The result of impaired inhibitory processing can be manifested in a variety of ways including increased errors of omission, perseverations, and/or intrusions.

The present research was designed to further study the role of inhibition in cognitive changes associated with advancing age. Because working memory has been hypothesized to be essential for many cognitive tasks, such as language comprehension, memory, and reasoning (Baddeley & Hitch, 1994; Just & Carpenter, 1992), the choice in the current investigation was to focus on age-related changes in working memory and the role of inhibition. To this end, two working memory measures were chosen. It will be argued that efficient inhibitory processes are a necessary component to successful performance on these tasks. Therefore, because the position taken for the current research is that older individuals have deficient inhibitory functions, it was predicted that they would show poorer performance on these working memory tasks, as compared to younger adults. In addition to an overall age-related decrement in performance, reduced inhibitory functioning would predict a specific pattern of responses to certain types of foils on these tasks. The analyses of these responses can provide stronger evidence that age-deficits in inhibition partially cause reduced performance on these tasks. The specific type of errors that were expected will be outlined later during the discussion of the working memory tasks.

Two studies were conducted in order to investigate more fully the role of inhibition in working memory performance. The first study had a two-fold goal. The first was to compare performance differences between young and old individuals on two working memory measures, with the expectation of age-differences in performance.

Although an overall age decline might be expected, it was hypothesized that inhibitory processes are more instrumental to performance in certain conditions of the tasks; thus, greater age-related changes were expected in these particular conditions. The second aim goal was to look for performance differences within an older sample to further understand the role of inhibition within this age group. This part of the study was a follow-up to an earlier study that demonstrated continuous changes in inhibitory functioning within an older age group (Persad, Abeles, Zacks, & Denburg, in press). A growing body of research suggests that performance on a number of cognitive and neuropsychological measures continues to decline with advancing age (Christensen, MacKinnon, Jorm & Henderson, 1994; Osterweil, Mulford, Syndulko, & Martin, 1994). These studies have generally divided the older population into a young-old group (typically between the ages of 60 and 74) and an old-old group (individuals over the age of 75). The usual findings are lowered performance rates on a variety of tasks in the old-old group as compared to the young-old group (Christensen et al., 1994; Osterweil et al., 1994; but see Speiler, Balota, & Faust, 1996). For the current study, older adults were divided into two groups, classified as young-old (between the ages of 60 and 74) and old-old (75 years and older). By assessing young-old and old-old groups, a clearer picture concerning age changes in inhibitory functioning can be drawn.

Although there is much support for the inhibition theory, it is not the only explanation of age-related cognitive changes. An alternative theory with considerable support is the processing speed theory (see Salthouse, 1996, for a review). The second study aimed to investigate the relative roles of processing speed and inhibition in accounting for age-related differences on the working memory data, by designing test conditions that result in different predictions based on the two theories. A review of this theory and its implications for the inhibition viewpoint will be presented later in the paper.

Measures of Working Memory

The two working memory tasks that were chosen for each study were the n-back task and the verbal item recognition task. The specific variations of the task used here have been used recently in the neuroimaging literature to identify the neuroanatomical regions that may be involved in working memory in young adults (Smith & Jonides, 1997). In the sections that follow, a brief description of the measures and previous results from related studies are presented. Then, the hypothesized contribution of inhibition to performance on these tasks is outlined, and predicted age differences are described.

N-back Task

The general procedure of the n-back task used here was patterned after one used by Smith and Jonides in their studies of the neuroanatomical regions involved in working memory (1997; Smith, Jonides, & Koeppe, 1996). In this task, letters were visually displayed one at a time in a continuous string. As each letter appeared, the subject responded (pressed the appropriate key) to indicate whether the current letter was the same as (i.e. same in identity) or different from one presented n positions earlier in the sequence. See Figure 1 for a visual representation of the task. For this study, only two conditions were administered, requiring a decision based on the match to the item 2-back or 1-back in the series. This task is usually regarded as a complex working memory task requiring the continual processing of items (Baddeley & Hitch, 1994; Just & Carpenter, 1992). With the presentation of each new letter, there is a need to update the contents of working memory while remembering the relative location of the appropriate items. In studies that have used variations of this task, one of the assumptions is that the longer the lag (i.e. the number of intervening items between the current item and the item presented n-back in the series), the greater the memory load in working memory (Dobbs & Rule, 1989; Smith & Jonides, 1997).

It is argued here that inhibition is one of the key components to successful performance on this task. With each new letter, as one updates the contents of working memory, one must suppress, or in a sense ignore, earlier presented items that are irrelevant to the current trial. The ability to suppress this information will aid in the efficient search of the most current letters and selection of the appropriate response. Otherwise, if suppression does not occur, the additional material in working memory can be distracting, making it more difficult to make a correct response presumably due to increased interference effects from this extraneous information that remains activated in working memory.

To analyze the task in more detail, let us follow the events that occur on a given trial of a 2-back condition. With the presentation of a new letter, the letter that was 2-back in the sequence on the previous trial is now in the 3-back condition. This letter is no longer relevant for the current trial and, it is argued, needs to be suppressed to prevent it from interfering with the other items currently in working memory. The greater the amount of distracting and potentially interfering information in working memory, the greater the potential difficulty in deciding whether a match has occurred. Thus, the presence of additional material can lead to slower response times and decreased accuracy on this task.

Given the hypothesis that the ability to suppress previous information declines with age, the prediction is that older adults will have relatively more difficulty deleting the irrelevant letters. With the resulting cluttering of working memory, older adults will find this task more difficult to perform. Therefore, the n-back task ought to be sensitive to age effects due to interference from the additional letters that remain activated in working memory for older adults. This increase in clutter also would be expected to hurt performance more in the more difficult 2-back condition, due to the larger amounts of material that need to be maintained and processed in working memory. Thus, larger age differences are predicted in the 2-back condition than in the 1-back condition.

To provide additional evidence for the role of inhibition in this task, an examination of the responses to different types of foils on the 2-back task can further illuminate the processes involved. If older adults have more difficulty suppressing/deleting earlier letters, these letters would remain in working memory causing interference. To test this hypothesis more directly, on a proportion of trials the probe letter would actually match the letter 3-back in the sequence. It is expected that when the current letter matches the one presented 3-back, older adults would show more errors of commission (increase in "yes" responses) and an increase in response time in comparison to trials when there is no match. In contrast, because young adults have more effectively inhibited the earlier stimuli, comparisons between the 3-back matching trials and trials on which there is no match should yield smaller or no performance differences.

Although age differences have not been investigated on the proposed version of the n-back task, age differences on tasks that used the basic procedure as the n-back task have been reported. Dobbs and Rule (1989) administered a variant of the n-back task to subjects ranging in age from 30 to 97, divided into five age groups by decade (the oldest age group was 70 and above). These authors wanted to design a working memory task that required the constant updating and processing of information. At the same time, they wanted a task that did not rely on verbal/reading ability like the typical working memory reading span measures or the computation span measures that rely on basic arithmetic skills. The researchers therefore presented digits one at a time, and, depending on the condition, instructed the participants to repeat the digit just heard (0-back), the one just prior (1-back) or the digit presented 2 trials back (2-back). Participants were administered all 3 lags, with a possible maximum score of 10 for each condition. They also administered measures of short-term memory, digit span forwards and backwards, and the Brown-Peterson task. Results revealed age differences only on the n-back task. Although all age groups showed a decline in performance with each increasing lag condition, the pattern of decline varied. The 30-, 40-, and 50-yr-olds showed similar declines across all lag conditions, whereas the 60-yr-olds performed significantly more poorly at lag 1 and 2 than the younger age groups. By contrast, the 70+-yr-olds showed even greater declines in performance than the 60-year-olds. Based on these findings, the authors concluded that age declines on the n-back task might be due to a difficulty in the ability to update or switch processes quickly.

See and Ryan (1995) used the n-back procedure with an older sample to investigate determinants of language difficulties that occur with age. These investigators were interested in studying the relative roles of generalized slowing, inhibition, and working memory as mediators of age differences on a variety of language tests. In this study the n-back task was one of the predictor variables, used as a measure of working memory, whereas the Stroop interference score was used as a measure of inhibitory functioning. Although the n-back task was not under direct study, the reported raw data and the data from the hierarchical regression analyses are informative. The n-back procedure used in that study was patterned after the one used by Dobbs and Rule (1989) but with two variations. Consonants were used instead of digits, and two additional lags were tested (3 and 4-back). Both the young and old group showed an overall decline in performance with increasing lag, with the older individuals exhibiting increasingly more difficulty across the lag conditions. Furthermore, when the proportion of variance accounted for by the n-back task was covaried out in a regression analysis, it was found that this working memory measure mediated some of the age-related decline in language performance (just as did the measures of speed and inhibition). What is of interest is that when either the speed or inhibition measures were first factored out before the n-back task, the proportion of age-related variance in working memory performance was no longer significant. This suggests that performance on the n-back task itself may be mediated in part by both speed of processing and inhibitory functioning.

In summary, there is evidence that old adults, in comparison to young, do experience more difficulty on tasks that presumably require the suppression of earlier material, as in the n-back task. These findings are consistent with the hypothesis that inhibitory functions become deficient with age. It is hypothesized that older adults will exhibit greater difficulty on the n-back task. Unlike previous studies that have only examined overall age differences in working memory, the use of familiar (i.e. recently presented) foils in the n-back task in the current study can provide additional evidence for the role of inhibitory processes (as opposed to processing speed or decreased working memory capacity; this point will be expanded later in the paper) and allow for a stronger claim to this effect. In addition, the use of the two older age groups will allow for a more refined examination of inhibitory functioning within an older sample.

Verbal Item-Recognition task

The verbal item-recognition working memory task (VRWM) modeled after Sternberg's short-term memory task (Sternberg, 1966) is also taken from the neuroimaging literature (Jonides, Smith, Marshuetz, Koeppe, & Reuter-Lorenz, 1998; Smith & Jonides, 1997; Smith et al., 1996). In a typical experiment, on each trial an array of letters is presented, followed by a probe letter after a specified delay. Upon presentation of the probe, one needs to decide whether or not the probe was a member of the target array. The task requires the participant to maintain the target array in working memory for the duration of the delay, then compare the letters in memory with the probe, and finally make the appropriate response. Sternberg (1966) used this procedure to study short-term memory search processes and found that as the number of items presented in the target array increased, the longer it took to respond to the probe. He interpreted this finding as support for the idea that memory search occurs serially and that one exhaustively searches all items in memory before making a response. Many of the earlier studies that have used this basic procedure to study age differences were interested in presumed serial scanning abilities. It has generally been found that as target set size increases, older adults take increasingly longer to respond to the probe than younger adults (Anders & Fozard, 1973; Anders, Fozard, & Lillyquist, 1972; Erikson, Hamlin, & Daye, 1973), leading to conclusions that search processes are slower in older adults. However, these findings leave open the question of what underlies the slowed search processes in older adults.

Results from more recent studies suggest that inhibition may play a role in successful performance on the VRWM. Jonides and his colleagues have used a modified version of the Sternberg task to investigate this role (Jonides et al., 1998). Using one set size, they presented the four target items simultaneously on each trial, with the probe matching the target array (positive probe) on half of the trials. To study inhibition, two conditions were designed that manipulated the type of probes in very specific ways. In the High-Recency condition, half of the negative probes (those not matching a target item) were actually members of the target array on the previous trial (designated recent negative probes). Although a "no" response was currently required, the authors hypothesized that subjects would have to inhibit a prepotent response tendency to respond "yes" because of the previous association to the earlier target array. The need to inhibit the 'yes' response should be demonstrated in longer response times and increased errors on these trials. In addition, half of the positive probes were also members of the previous target array (recent positive probes). In this case, because the response was already primed, facilitation would be expected, manifested in shorter response times. In the Low-Recency condition probes were not allowed to overlap with targets from the two previous trials, thereby reducing the need for inhibition. Results generally confirmed the expectations. Response times were slower and responses less accurate for the recent negative probes in the High-Recency condition compared to the negative probes in the Low-Recency condition. These results supported the view that inhibitory processes were engaged in this task. However, facilitation effects (represented by faster response times in the recent positive condition as compared to the positive condition) were not found.

In a follow-up study, Jonides and colleagues (Jonides, Marshuetz, Smith, Reuter-Lorenz, Koeppe, & Hartley, 2000) tested a group of older individuals on the same task. Results demonstrated that the older adults exhibited increased interference effects in the recent negative condition as compared to the younger adults. The authors interpreted these findings to support the notion that inhibitory processes become less efficient with advancing age.

A similar result was obtained in the directed forgetting study with older adults reported earlier in this paper (Zacks et al., 1996). Of relevance to this discussion is the use of an immediate recognition test in the third experiment of this study. After each presentation of the TBF and TBR words, a recognition test was administered. Participants were instructed to respond yes if a presented probe was in the TBR set of words. On some trials, the probe was actually a member of the TBF list, whereas on the remaining trials the probe was a new word. Results showed that younger adults had significantly slower reaction times to the TBF probe as compared to the probe that was neither a TBR nor a TBF item. These results are similar to Jonides et al.'s findings (2000) and to other findings that have used this recognition procedure to study inhibition in young adults (Bjork, 1989). With respect to the older adults' performance, it was expected that the inefficient inhibitory processes would result in a greater increase in reaction time when the probe was a TBF item as compared to a new item. Results confirmed these expectations, supporting the claim that older adults have greater difficulty suppressing information in working memory that becomes irrelevant to the task.

Although the VRWM task proposed in the current study does not explicitly instruct the participant to forget items from earlier trials, as in the directed forgetting task, there is an implicit awareness that one needs to ignore earlier information and instead attend to the current target array for successful performance (Bjork & Bjork, 1996). An inability to suppress the items from the earlier trials on the VRWM, presumably leaving these items activated in working memory, can lead to interference effects from the presence of this additional material. It follows then, that with the presumed deficit in inhibitory functioning, older adults will have more difficulty on the inhibition trials (i.e. recent negative), as evidenced by longer response times and lower accuracy. This was the very result found by Jonides and colleagues (2000).

Although additional studies would have to be conducted, it is possible that inhibitory deficits could partially account for the reported age deficits from the earlier studies of search processes (i.e. search rate in the Sternberg task) in older adults. In these studies, typically, multiple target lists are presented to participants with little delays between trials. The slowing in response time in older adults may actually partially be a result of inefficient inhibitory processes rather than a slowed serial search process per se. Items from the earlier trials may have remained activated in working memory, causing interference effects and thus making it difficult to respond to the probe (May, Hasher, & Kane, 1999). It would be important to design studies to control for the effects of interference in the Sternberg task, before drawing conclusions about search processes in older adults.

In summary, as a result of hypothesized inhibitory deficiencies that accompany old age, it is predicted that older adults will exhibit more difficulty than young adults on two working memory tasks. Specifically, performance should be differentially worse in conditions where inhibitory processes are assumed to be more important for successful outcomes. Finding a greater decrease in performance on trials that require greater inhibitory control in both working memory tasks would offer especially strong support for the inhibition theory of aging deficits in working memory. In contrast, the processing speed theory (Salthouse, 1996) does not necessarily predict differences between trials that involve familiar foils (the 3-back match condition in the n-back task, and the inhibition trials in the VRWM task) as opposed to those trials that don't employ this manipulation. In addition, supporting previous findings of a continuous decline in inhibitory functioning within an older population, old-old individuals are expected to do more poorly than young-old individuals.

The Prefrontal Cortex and Inhibition

In addition to providing a test of the inhibition deficit hypothesis, the rationale and design of the current studies were influenced by findings from the neurocognitive literature. Neuroimaging studies suggest that the prefrontal cortex, especially the dorsolateral aspect, is involved in both working memory and inhibitory functioning. (Chao & Knight, 1997; Fuster, 1997;Gevins & Cutillo, 1993; Jonides et al., 2000; Jonides et al., 1998; Schumacher, Lauber, Awh, Jonides, Smith & Koeppe, 1996; Smith & Jonides, 1997; Smith et al., 1996). Both PET and fMRI studies have demonstrated increased activation of the dorsolateral prefrontal cortex (DLPFC) during the n-back task (see Smith

& Jonides, 1997 for a review) as part of a larger neural network that has been proposed to subserve a working memory system. The role of the PFC in inhibitory processes has been examined more fully with the VRWM task. In the Jonides et al. study (1998) described above, young participants showed an increase in activation in the left lateral prefrontal cortex but only during the inhibition trials (recent negative trials), suggesting a role for the PFC in inhibition. In contrast, not only did the older adults demonstrate behaviorally more problems inhibiting responses in the follow-up study (Jonides et al., 2000), no reliable activation in same prefrontal region was found.

Clinical research studies also lend indirect support for the possible role of the prefrontal cortex in working memory and inhibitory processes. Findings from lesion studies have shown that patients with frontal lobe lesions have particular difficulty inhibiting responses and suppressing previous response sets (Cronin-Golomb, 1990; Stuss & Benson, 1984). Impairments in executive functions, including working memory tasks have also been reliably demonstrated in these patients (Lezak, 1995).

In addition, neuropsychological and neuroanatomical evidence suggest that there is a differential decline in the functioning of the frontal lobes associated with the aging process. Atrophy is more marked in the frontal lobes compared to other cortical areas (Coffey, 2000; Haug & Egger, 1991), accompanied by a reduction in cerebral blood flow (Gur, Gur, Obrist, Skolnick, & Reivitch, 1987; Pietrini & Rapoport, 2000), and older adults have difficulty on neuropsychological tasks that are assumed to reflect frontal lobe functioning (Cronin-Golomb, 1990; Shimamura & Jurica, 1994). Chao and Knight (1997) have also demonstrated more directly a relationship between inhibitory functioning, age, and the prefrontal cortex. Using electrophysiological measures, changes in amplitude were demonstrated in the prefrontal cortex in older adults in conjunction with behavioral measures of decreased inhibitory functioning.

Although the main focus of this paper is the relationship between inhibitory processes and working memory performance in older adults, a neuropsychological measure that has been associated with frontal lobe functioning was administered in Study 1 to provide indirect evidence of the link between the frontal lobes and performance deficits seen on the working memory measures due to aging. In particular, the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Tally, Kay, & Curtis, 1993; Milner, 1964), a test that has been used as an indicator of frontal lobe functioning (see Anderson, Damasio, Jones, & Tranel, 1991, for an opposing view) was used. Recently, PET data have shown that the DLPFC is activated during the WCST (Berman, Ostrem, Randolph, & Gold, 1995). In a previous study, following the argument of Arbuckle and Gold (1993; Gold & Arbuckle, 1995), we have argued that inhibition is one of the processes that is measured by performance on the WCST (Persad et al., in press). As a result, it was expected that performance on the working memory measures (that are thought to be mediated, in part, by inhibition) and the WCST would be significantly correlated. If this relationship were borne out, it would provide indirect evidence for the role of the DLPFC in inhibition.

STUDY 1

METHOD

Participants

Twenty-one younger adults under the age of 30 and 41 adults over the age of 65 were tested. The older adults were further divided into two groups based on age. Twenty adults between the ages of 60 and 74 were classified as young-old and twenty-one adults over the age of 75 were classified as old-old. The young adults were undergraduate students who received course credit for their participation. The older adults were recruited from the local community and were paid ten dollars for their participation. Subjects were excluded on the basis of a history of stroke, head injury, significant periods of loss of consciousness, attention deficit disorder or a learning disability, or other health problems that have been documented to affect general cognitive functioning. One young adult with an ADD diagnosis and one old-old adult with carpal tunnel syndrome who was unable to make the required motor response were excluded, resulting in equal sample sizes across the three age ranges. In addition, the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was administered to the older adults as a screen for possible cognitive impairment. On this test a score of 23 or less is an indication of the presence of cognitive difficulties. No older adult was excluded based on this measure; MMSE scores for the young-old group were 27.2 (S.D. = 1.61) and 27.6 (S.D. = 1.64) for the old-old group.

Data on mean age, education and vocabulary ability are provided in Table 1. Results from a one-way ANOVA demonstrated significant differences in education (F $(2,57) = 4.47$, $MSe = 5.70$, $p<.00$) between the three age groups. Bonferroni post hoc analyses revealed significant differences in education between the young and the old-old group, with the older adults having achieved a higher level of education. Verbal ability as measured by the Vocabulary test from the Shipley Institute of Living Scale (Shipley, 1946) demonstrated significant differences between the three groups (F $(2, 54) = 9.76$, $MSe = 17.54$, $p<.00$). Post Hoc analyses showed that vocabulary scores for the old-old group were significantly higher than the two other age groups, but the young-old and the young were not significantly different from each other.

In addition, the presence of depressive symptomatology was assessed through self-report questionnaires. The Beck Depression Inventory (BDI; Beck, 1978) was used with the young adults and the Geriatric Depression Scale (GDS; Brink et al., 1982) was used with the older adults. On both instruments a score of 10 or above is used an indication of depression. Scores on these measures for the three groups were Mean = 3.3 (S.D. = 2.28) for the young group, Mean = 4.9 (S.D. = 3.65) for the young-old and Mean = 3.7 (S.D. = 2.89) for the old-old group. None of the young received a score above the cut-off, 2 of the young-old (scores of 12 and 14 respectively, classification as mild depressive symptoms) and 1 of the old-old (score of 11, very mild depressive symptoms) were above the cut-off. Inspection of the data from these 3 subjects revealed no apparent differences from their relevant age groups. All analyses were performed with and without including these subjects with similar results. Thus, to maintain equal n's across the groups, these 3 subjects were retained in all of the analyses described below.

Measures

Working Memory Measures

Administration of the working memory measures was counterbalanced. Half of the participants were given the item recognition task first, followed by the n-back task; the other half were given the reverse order. In addition, counterbalancing was done for the n-back task; the 1-back condition was administered first for half the subjects, and the other half were given the 2-back first.

N-back task

Materials

All 21 consonants were used as stimuli. Five lists of letters were constructed for the 1-back condition, each of which had 36 letters. Within a list, letters were not repeated unless in the positive or recent negative condition. For each list there were: 8 positive trials in which the letter matched the one presented just before, or 1-back, in the sequence; 22 negative trials, in which the letter did not match the item 1-back; 6 recent negative trials in which the letter actually matched the item presented 2-back in the sequence. The first item in the list was considered filler. This led to a total of 40 positive trials, 110 negative trials, and 30 recent negative trials.

The 2-back stimuli were constructed in a similar fashion. Another filler was added at the beginning of each list for a total of 37 items. Each string included 8 positive trials; in this case a positive trial was one in which the letter matched the one presented 2-back in the sequence. There were 6 recent negative trials defined as trials in which the letter actually matched one presented 3-back in the sequence, still requiring a "no" response. Twenty-one negative trials as well as two 1-back (foil) trials were included. Just as before, a 1-back trial was defined as one in which the letter matched the 1-back. This condition was added to check that the participant was performing the task, and not just responding indiscriminately based on simple repetition of a stimulus. Across the five lists, there were a total of 40 positive, 105 negative, 30 recent negative and 10 foil trials.

Procedure

For both the 1 and 2-back conditions, a series of practice trials were administered followed by the test. The practice consisted of three different components. First the individual was shown a series of numbers printed on a card. The presentation allowed the participant to see all of the numbers at the same time, while making the appropriate yes/no response. Then numbers were presented on cards one at a time, and again the subject was asked to make the appropriate response. Numbers were used initially in an attempt to reduce possible proactive interference effects. Finally, a practice series of letters was presented on computer. Feedback regarding performance was given and practice trials were repeated as necessary until the individual appeared to understand the task and achieved a perfect score.

Stimuli were presented in the center of a computer screen. Each trial was 3000 msecs in duration: a stimulus presentation of 1000 msecs followed by a 2000 msec delay during which time a cross was presented on the screen. Participants were instructed to press the appropriate key on a button box as quickly as possible. For half of the subjects, the yes response was made with the right index finger and the no response with the left index finger, with the remaining subjects receiving opposite instructions. Subjects were instructed to respond "no" to the first one (1-back) or two (2-back) letters in a list. A one-minute rest period was provided between each list presentation. Response times measured in milliseconds and accuracy were recorded.

Verbal Item Recognition test

Materials

320 four-letter nouns were chosen from the Kuchera and Francis (1967) frequency norms ranging in frequency from 5 to 393. These were used to develop eighty arrays, each containing four words. Each array was randomly assigned to one of the four experimental conditions. Each word was presented only once, unless in the interference or facilitation condition. Four different lists were developed that counterbalanced the stimulus arrays across the four experimental conditions.

Procedure

Each array was presented in a 2x2 matrix in the center of the computer screen for 2000 msecs. This was followed by the presentation of a cross for 2500 msec. Then the target word was presented and participants were instructed to decide if the probe word was in the array. Just as in the n-back task a button press was used for responding; for half of the individuals the left button was used for "yes" and the right button was "no" with the reversed order for the remaining participants. A practice sequence of five trials was administered to ensure comprehension.

The 80 arrays were presented in pseudorandom order. For 40 trials the probe matched one from the stimulus array. On half of these trials, the probe was a member of only the current array (positive condition). For the other half of these trials the probe was also a member of the array from the previous trial (recent positive condition). On the negative trials half of the probes were new words, never presented on any previous trial (negative condition). The remaining probes were members of the previous array, but not the current one thereby requiring a "no" response (recent negative condition).

Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Tally, Kay, & Curtis, 1993; Milner, 1964).

The participant was given a set of 128 cards on which were printed one to four symbols of either stars, crosses, triangles or circles in one of four different colors. The task was to place each of the cards under one of four stimulus key cards according to a principle that the person must deduce from the pattern of the examiner's responses to the person's placement of the cards (i.e. color, form, or number had to be matched). After a run of ten correct placements in a row, the to-be sorted principle was changed, and this was indicated to the subject only in the changed pattern of "right" and "wrong" feedback. This was continued until six category shifts were achieved or all cards were used. Although a variety of indices can be obtained from this task, findings from the neuropsychological literature have demonstrated that the number of perseverative responses (defined as a response based on a sorting strategy that was previously deemed incorrect) exhibited on the WCST is most highly correlated with frontal lobe functioning (Lezak, 1995). The perseverative response score was used in subsequent analyses with higher scores representing greater impairment.

RESULTS

Unless otherwise indicated, significance levels were set at $p \leq .05$.

N-back task

Reliability estimates were first computed for the n-back reaction time results for each age group separately. Only the response times for correct responses were included in the reliability analysis. An inter-item analysis was performed by comparing results from the 5 presentation lists and computing an alpha score. Reliability as measured was consistently high for all three age groups in both the 1-back and 2-back conditions. In particular, for the 1-back condition, an alpha of 0.94 was obtained for the young adults, 0.96 for the young-old, and 0.97 for the old-old. Similar results were obtained for the 2-back task (alpha=0.96 for the young group, 0.94 for the young-old and 0.94 for the old-old).

Reliability estimates for the accuracy data were computed the same way. For the 1-back condition an alpha of 0.57 was obtained for the young group, 0.84 for the young-old, and 0.81 for the old-old. The 2-back results were 0.77 for the young, 0.77 for the young-old, and 0.82 for the old-old. The low reliability estimate for the young adults in the 1-back condition is due to a problem of range restriction in the results. The young adults were at ceiling, making very few errors and the resulting restriction in variation led to a underestimate of the reliability of the measure.

Tables 2 and 3 depict the raw response time and accuracy data for the 1-back and 2-back tasks across the three age groups. The reduced inhibition theory of aging would predict poorer performance on this task in the older age groups, particularly in the 2-back condition. In order to examine this hypothesis, first mixed 3 (age) X 2 (n-back task: 1-

back vs. 2-back) X 2 (condition: positive vs. negative) repeated measures ANOVA's were conducted separately for the response time and accuracy data.

An ANOVA of the accuracy results found all comparisons to be significant, including the three way interaction between age, n-back task, and condition, [F (2,57) = 3.290, MSe=26.91, eta^2 = 0.103]. In order to more fully understand the three-way interaction, two-way ANOVA's were conducted for the 1-back and 2-back task separately. In the 1-back task, only the condition effect was significant, [F (1,57) = 75.41, MSe = 24.32, eta^2 = 0.57], indicating that overall participants were less accurate in the positive condition than the negative condition. No age or age X condition effects were significant. Results were different for the 2-back task. A significant condition effect, [F (1,57) = 221.54, MSe =43.73, eta^2 = 0.80], age effect, [F (2,57) =8.32, MSe =53.34, eta^2 = 0.23], and an age X condition effect [F (2,57) = 5.94, MSe =43.73, eta^2 = 0.17] were found. There were no accuracy differences between the three age groups in the negative condition; however, both of the older-age groups made significantly more errors in the positive condition compared to the young.

For the response times, only data from correct responses were included in all subsequent analyses. Results of the response time data found an overall task effect; participants were slower to respond in the 2-back in comparison to the 1-back condition, [F (1,57) = 95.37, MSe= 14897.72, eta^2 = 0.63]. The age effect was also significant, [F (2,57) = 8.712, MSe = 43327.99, eta^2 = 0.23]. Tukey's honestly significant difference (Tukeys HSD) post hoc analysis demonstrated that the young group responded significantly more rapidly than either of the two older groups, but the two older groups were not significantly different from each other.

Taken together these results demonstrate that the older adults have more difficulty than the younger adults do on the n-back task, particularly in the 2-back condition. The reduction in accuracy and slower response times in the 2-back task is consistent with the view of reduced inhibitory processing in older adults. Analysis of the recent negative condition can further lend support for this view. As the next step, comparisons between the negative condition and the recent negative condition were performed.

Inhibition Comparison: Accuracy

An age (3 age groups) X n-back (1 vs. 2) X condition (recent negative vs. negative) analysis was performed with the accuracy data. All main effects and interactions were significant except for the three-way interaction (power = 0.46). Results for the accuracy data showed a significant main effect for age [Young M = 92.94, Young-old M = 87.85, Old-Old M =88.01; F (2,57) = 4.79, MSe =139.47, $eta^2 = 0.14$], n-back effect [1-back M = 97.21, 2-back M = 82.00; F (1,57) = 166.37, MSe =83.47, $eta^2 = 0.75$] and n-back X age interaction [F (2,57) = 2.96, MSe =83.47, $eta^2 = 0.09$] with the two older groups overall making more errors in the 2-back task compared to the young. The condition [negative M = 98.99, recent negative M = 80.21; F (1,57) = 176.34, MSe =119.95, $eta^2 = 0.76$] and condition X age interaction were also significant [F (2,57) = 3.81, MSe =119.95, $eta^2 = 0.12$] indicating that the two older groups made more errors in the recent negative condition compared to the young adults (Figure 2). The n-back X condition interaction was also significant [F (1,57) = 159.63, MSe =74.39, $eta^2 = 0.74$]. Tukey's post hoc analysis showed that the young adults were more accurate than the two older groups, but no difference between the two older groups was evident. To explore further the possible relationship between age and performance within the older age range correlations were computed between age and accuracy scores for the recent negative and negative conditions just for the two old groups combined. None of the correlations between age and the recent negative and negative conditions for either n-back condition approached significance.

Given the lack of age differences between the two older groups, these data were collapsed into a single old group and the analyses were repeated to increase the power of the tests by increasing sample size. This time, all of the comparisons were significant including the three way interaction (i.e. age X n-back X condition; F (1,58) = 4.45, MSe =73.52, $eta^2 = 0.07$). In order to more fully understand this interaction separate two-way ANOVA's were conducted for the 1-back and 2-back condition separately. In the 1-back task, only the main effect of condition was significant [F (1,58) = 15.62, MSe =29.48, $eta^2 = 0.21$] demonstrating that overall accuracy was lower in the recent negative condition in comparison to the negative condition. Although not significant there was a trend for an overall age effect ($p \leq 0.07$, $eta^2 = .06$) with the older adults experiencing more difficulty (i.e. less accuracy) than the young. In comparison, the 2-back found a significant age effect [Young M = 87.3, Old M = 79.34; F (1,58) = 9.04, MSe =187.10, $eta^2 = 0.14$], condition effect [negative M = 98.64, recent negative M = 68.00; F (1,58) = 154.58, MSe =161.96, $eta^2 = 0.73$] and condition X age interaction [F (1,58) = 7.19, MSe =161.96, $eta^2 = 0.11$]. In particular, in the 2-back task the older adults experienced relatively more difficulty in the recent negative condition than the young adults did with no age differences in accuracy in the negative condition.

Inhibition Comparison: Response time

A similar analysis (as computed for the accuracy data) was performed for the response time data. First an age (3 age groups) X n-back (1 vs. 2) X condition (recent negative vs. negative) analysis was done. The main effects of age [Young M = 638.82, Young-Old M = 791.87, Old-Old M =766.26; $F (2,57) = 8.89$, MSe =60468.09, eta^2 = 0.24], n-back [1-back M = 646.2, 2-back M = 818.43; $F (1,57) = 93.82$, MSe =18969.1, eta^2 = 0.62] and condition were significant [negative M = 665.99, recent negative M = 798.64; $F (1,57) = 187.19$, MSe =5640.44, eta^2 = 0.77]. In addition the n-back X condition was significant [$F (1,57) = 6.71$, MSe =3179.97, eta^2 = 0.11]. No other interactions were significant. Post hoc analyses once again found no differences between the two older age groups; however these two groups were significantly slower than the young adults. Correlations were computed for age and the recent negative and negative response times within the older age range to further examine the relationship between age and performance. None of the correlations with age were significant for either n-back task.

The two older age groups once again were collapsed into one group. Results from the ANOVA revealed similar results. Main effects of age, n-back, and condition were all significant. The n-back X condition interaction was also significant [$F (1,57) = 4.13$, MSe =3150.29, eta^2 = 0.07]. In addition, the age X condition was significant with the older adults experiencing relatively more difficulty (i.e. slower response times) in the recent negative condition than the young [$F (1,57) = 3.65$, MSe =5572.13, eta^2 = 0.06] with smaller age differences shown in the negative condition.

Item Recognition task

Reliability estimates for the response time data were first done by conducting a split half analysis on the response time data for correct trials for each age group. Alpha coefficients indicated satisfactory reliability for all three age groups (young, alpha = 0.97; young-old alpha = .91; old-old, alpha =. 90). Alpha coefficients for the accuracy data were –0.01 for the young, 0.87 for the young-old and 0.83 for the old-old. The lack of a relationship for the young adults is due to the very restricted range of accuracy scores in this measure. At most only 4 errors were made by the young adults (only 2 subjects) across each half, making it difficult to compute the alpha coefficient. With the young adults essentially at ceiling on this task, it is felt that the obtained accuracy data is reliable for this group.

Raw data for the verbal item recognition test is presented in Table 4. The response time data were first trimmed to eliminate possible outliers due to anticipatory responding or other factors such as distractions[1]. Those responses that were more than 3 standard deviations from the mean were trimmed. Few responses were eliminated based on this procedure. Specifically, 1.5% (S.D. = 1.34) of the responses were removed from analyses for the young group, 0.88% (S.D. = 1.10) for the young-old group and 1.96 (S.D. = 1.47) for the old-old group.

First an overall analysis was conducted looking at all four conditions across the three ages for accuracy and response time data separately. An age X condition ANOVA was first conducted with the accuracy data. Only the condition effect was significant [F (3,171) = 16.49, MSe =46.38, $eta^2 = 0.22$] with lower performance in the recent negative condition across all age groups. A similar analysis for the response time data found a significant condition effect [$F(3,171) = 45.52$, $MSe = 7767.41$, $eta^2 = .44$] and age effect [$F(2,57) = 16.21$, $MSe = 80237.27$, $eta^2 = 0.36$]. Post hoc analysis found no differences between the two older groups, whereas they were both slower than the younger adults.

Because the stimuli used in the item recognition task were words, level of vocabulary skill could be a factor in performance on this task[2]. Thus, all analyses were repeated using the Shipley vocabulary score as a covariate. Overall, covarying verbal skill did not affect the results except where noted below. Repeating the age X condition analyses, using vocabulary skill as a covariate did not alter the results for either the accuracy or response time data.

Inhibition Comparison

It was hypothesized that the older adults should experience relatively more difficulty in the recent negative condition as compared to performance in the negative condition in the item recognition task, presumably due to age-related inhibitory deficits resulting in interference effects. Due to the lack of differences between the two older age groups, these data were first collapsed and analyses were conducted looking just at the comparison between the recent negative and negative conditions. An age X condition (recent negative vs. negative) comparison was first done for the accuracy data. A main effect of condition was found with poorer performance seen in the recent negative condition overall [negative $M = 98.13$, recent negative $M = 90.38$; $F(1,58) = 52.04$, $MSe = 30.77$, $eta^2 = 0.47$] whereas the main effect for age showed a trend towards significance ($p \leq 0.08$, $eta^2 = .05$).

A similar analysis was done for the response time data. In this case a significant main effect for condition [negative $M = 782.08$, recent negative $M = 932.97$; $F(1,58) =$

86.35, MSe =7031.29, $eta^2 = 0.60$], and age [Young M = 743.74, Old M = 971.3; F (1,58) = 27.17, MSe =50441.62, $eta^2 = 0.32$] were found as well as a trend for the age X condition interaction [$p \leq 0.06$, F (1,58) = 3.58, MSe =7031.29, $eta^2 = 0.06$, power = 0.46]. Although only approaching significance these data suggested that the older adults experienced more difficulty in the recent negative condition as evidenced in slower response times.

A similar pattern of results was obtained for both the accuracy and response time data when vocabulary skill was used as a covariate in the analyses.

Facilitation Comparison

Although not the focus of the study, following Jonides et al.'s (1998) design of the item recognition procedure, possible facilitation effects were examined by comparing performance in the positive and recent positive condition. In the recent positive condition, items are presented twice, once in the preceding array and then again immediately after in the target array. This repetition of a stimulus may maintain activation of the item, possibly leading to better performance on these trials. Again the two oldest age groups were first collapsed for the analyses. None of the comparisons in an age X condition ANOVA of the accuracy data were significant. The response time data showed a significant effect of condition (F (1,58) = 4.89, MSe=2220.24, $eta^2 = 0.08$] demonstrating that response times were faster in the recent positive condition compared to the positive condition [this is contrary to results reported by Jonides et al. who did not find facilitation effects for their young adults (1998)]. A main effect of age was also found [F (1,58) = 27.89, MSe =43081.87, $eta^2 = 0.33$] demonstrating that overall the older adults were slower than their younger counterparts. Although in this study facilitation effects were demonstrated by faster rates of responding, there were no age differences in this effect

As in the inhibition comparison, no change in results were found when vocabulary skill was covaried.

Relationship to WCST Measures

The possible role for the prefrontal cortex in inhibitory control of performance on the working memory measures was explored by examining the relationship between the WCST and the two working memory measures. Means and standard deviations for the WCST are shown in Table 5. A one-way ANOVA of the Perseverative response score revealed a significant age difference, [$F(2,55) = 3.54$, $MSe = 332.05$]. Tukey's HSD post hoc analysis showed that the old-old group had more perseverative responses than the young group, while there was a trend for the old-old group to be significantly different from the young-old group ($p < 0.09$). Bivariate correlations were computed between the number of perseverative responses obtained on the WCST and the accuracy and response time scores in the recent negative condition for the n-back and the item recognition task. Perseverative responses were not significantly correlated with accuracy or response time in the 1-back task or the item recognition task. In the 2-back condition, although there was not a significant correlation with response time, perseverative responses were significantly correlated with accuracy ($r = -0.26$) indicating the more difficulty experienced on the WCST, as represented by a higher perseverative response score, the greater the interference effect in the 2-back condition as indicated by lower accuracy. Perseverative responses were not correlated with accuracy or response time in any other condition (e.g.

positive, negative, recent positive) with the exception of a negative correlation with accuracy in the positive condition in the 2-back task ($r = -0.33$).

DISCUSSION

Results from the n-back task support the hypothesis that age-related deficits in inhibition contribute to age differences in working memory performance. Less efficient inhibitory functioning would lead to greater difficulty supprssing information from working memory, thus allowing irrelevant material (in this case letters from earlier trials) to remain in working memory leading to performance decrements due to increased interference effects. This interference effect would be expected to be greater in the more difficult 2-back task. The results showed that overall, older adults had more difficulty on the n-back task than younger adults, as reflected both in slowed response time and decreased accuracy. As predicted by the inhibition theory, these age differences were more pronounced in the 2-back condition than in the 1-back condition.

Although these data are consistent with the inhibition view, the pattern of results also could be partially accounted for by other theories, such as an age-related decrease in working memory capacity. However, examination of responses in the recent negative condition lends additional support for the inhibition hypothesis. If older adults have more difficulty suppressing or deleting the previous n-back item from working memory because of inefficient inhibitory processes, then older adults would be expected to show greater interference effects, as reflected both in response time and accuracy results, when the target item actually matched the n +1 back item. This is what was found. Compared to younger adults, the older adults experienced increased interference in the recent negative condition than in the negative condition, particularly in the 2-back task. In effect, these results imply that older adults held more information in working memory compared to younger adults (predicted by the inhibition theory) rather than less information as would be predicted if working memory capacity decreased with age.

However, results from the verbal item recognition task did not provide strong support for the inhibition hypothesis of aging. Overall, performance was lower in the recent negative condition as compared to the negative condition, but results were only suggestive of an age difference in this effect. In particular, results from the inhibition comparison showed a trend for greater age related difficulties in the recent negative condition as compared to the negative condition; however, the difference was not statistically significant. In contrast, Jonides et al. (2000) found evidence for age differences in the recent negative condition. There are a number of notable differences in procedure between the current study and the one by Jonides et al. that may account, in part, for this difference. The current study used words as stimuli, whereas Jonides et al. used single letters. The use of words may have provided enough context for the older adults to facilitate recognition, overcoming any possible decrements that might have occurred due to decreased inhibition. Unlike letters which, being only 26 in number, required frequent repetition (and most likely increasing interference effects), no word was repeated in the study arrays (except for items in the recent positive and recent negative conditions), making each stimulus relatively unique from each other and potentially easier to discriminate. Earlier studies have shown that age differences in inhibition can be attenuated if not eliminated by slight changes in the task (such as location of distracting stimuli) that allow for easier discrimination between stimuli, reducing the role of inhibitory processes for successful performance (Carlson et al., 1995; Connelly & Hasher, 1993).

In addition, contrary to earlier findings in young individuals (Jonides et al. 1998), there was a facilitation effect in both the young and old age groups, with no age differences in the size of the effect.

An alternative explanation for the lack of age differences in the current study pertains to the power of the current study to detect an age effect. In the Jonides et al. study (2000), because the focus was on the correlates of performance and neuroimaging results, participants in their study were extensively trained to ensure a high level of accuracy across all conditions and to reduce error variance prior to conducting the study, making any age differences more detectable by statistical analysis. The subjects from the current study did not have the benefit of prior training. Inspection of the data reveals patterns consistent with Jonides et al.'s study, with the older age groups experiencing greater amounts of interference as reflected in longer response times and lower accuracy (in fact the present study demonstrated numerically larger interference effects for the older age groups), yet the effects here were not statistically significant.

Limited indirect evidence was also provided for the possible role of the prefrontal cortex to inhibitory functioning. Perseverative responses from the WCST, a measure that is often argued to be associated with dorsal lateral prefrontal functioning, was correlated with performance on the 2-back task for the inhibition condition (i.e. recent negative). This relationship was not evidenced with the 1-back or the VRWM. The 1-back is an easier task, and it can be argued that inhibition may not be as crucial a process to this task as the 2-back, when more material is dealt with in working memory. In contrast, although a significant relationship was expected between the WCST and the VRWM interference scores, since the expected interference effects associated with age were not clearly demonstrated on the VRWM task, it is not surprising that there is a lack of relationship between these two measures making interpretation of this null effect difficult.

One final point of the first study is the lack of expected age differences between the two older groups. This result is contrary to findings reported by a number of researchers, including those by the author (Persad et al., in press). But, other studies have failed to find age differences within the older age groups (Keys & White, 2000; Speiler et al., 1996). At this time, it is unclear why there is this discrepancy in age differences. One factor may be differences in task difficulty, although in the current study the n-back task could be argued to be a much more difficult task than the item recognition task. Yet neither task showed the expected age differences between the older age groups. If continued age declines within the older population are found consistently with only a subset of cognitive tasks, then this pattern of results would suggest more focal changes that occur within certain systems as opposed to a global process that is believed to underlie all age-related cognitive changes.

STUDY 2

Although one can argue for the role of inhibition in the VRWM and n-back tasks by demonstrating that predicted results based on the theory do occur, it is also important to demonstrate that other theories cannot adequately account for the results. One such theory is the processing speed theory, championed by Salthouse and his colleagues (see Salthouse 1996 for a review). According to the processing speed theory, as one ages, there is an accompanying generalized slowing of cognitive processes, leading to performance decrements on a variety of tasks. The effects of slowing result from two proposed mechanisms. The first is the limited time mechanism. Important cognitive processes are assumed to operate more slowly with increased age, which can reduce performance on tasks requiring rapid on-line processing, as in reaction time measures or language comprehension. Slowed initial processes also will cause difficulties in later stages of processing, not just because of time constraints but because of the limited or incomplete information that arises from the earlier stages. The second mechanism, related to the first, is called the simultaneity mechanism. Higher level, more complex cognitive processes are assumed to integrate and evaluate products of earlier processes. For this stage to be effective, the information must be simultaneously available. If, however, information is not readily available at the same time due to slowed processing effects, the final products of the higher level processes may be inadequate.

Like the inhibition theory, the processing speed theory has garnered considerable support. Many of the studies that have evaluated the role of processing speed have used different types of cognitive tasks along with measures of perceptual speed. Performance on the perceptual speed measures has been taken as an indicator of processing speed. The general analytical procedure used in these studies is hierarchical regression analysis, which shows that the perceptual speed measures mediate much of the relationship between age and the cognitive task in question. Measures of processing speed have been found to be significant mediators of a variety of cognitive tasks, including working memory (Salthouse & Meinz, 1995), arithmetic (Salthouse & Coon, 1994), paired associate learning (Salthouse, 1993) and free recall (Salthouse, 1993; 1994; Salthouse & Coon, 1993). One study in particular has found that measures of perceptual speed account for as much, and in some cases more, of the age-related variance on two working memory span measures than a measure of inhibition (Salthouse & Meinz, 1995).

It is important to note, however, that two recent studies have called into question the validity of the perceptual speed measures as relatively pure measures of processing speed (Lustig, Tonev & Hasher, 2000; Tonev, Lustig & Hasher, 2000). It has been demonstrated that age differences in performance on the variety of tasks generally used as measures of processing speed (letter and number comparison tasks, symbol digit substitution, arrow task) are in part a result of interference effects that occur as a result of the way the tests are administered. Typically items on perceptual speed measures are presented simultaneously, and age differences are consistently found. However, when items are presented one at a time, age differences in performance are much smaller, suggesting that older adults are more vulnerable to visual distraction, as reflected by relatively poorer performance. This susceptibility to visual distraction in older adults is consistent with inhibitory declines associated with age.

More recently the results from a number of studies have suggested that both generalized slowing processes and declines in inhibitory functioning must be taken into consideration to provide a fuller account of age-related deficits in cognition. As described above, See and Ryan (1995) found that both speed and inhibition were significant independent sources of the age-related variance on their battery of language tasks. Persad et al. (in press) showed that both measures of reading speed and inhibition accounted for a significant proportion of the age-related variance on a complex attention task and a verbal memory task. Nettelbeck and Rabbitt (1992) reported that measures of processing speed predicted only some of the age-related variance on a variety of cognitive tasks (including tests of recognition memory, list learning and free recall of 30 nouns), suggesting that slowed processing rate in older adults does not fully account for age-decrements in performance on these tasks. After controlling for level of complexity across tasks of processing speed and executive functioning, Keys and White (2000) also found that although processing speed accounted for a significant amount of the variance in the executive tasks, age was still a significant contributor.

West and Baylis (1998) have also investigated the relative contributions of slowing and inhibition to performance on the Stroop task. For the standard administration of the Stroop task, measures of perceptual speed accounted for a significant proportion of the age-related variance in the interference score. This, however, still left a significant proportion of unexplained variance. They then administered a variation of the Stroop color-word task. Some words were presented in their respective color (congruent trial) whereas other words were presented in the usual way (i.e. a different color; incongruent trial). Incongruent and congruent trials were mixed during presentations. However, two conditions were administered that varied the proportion of congruent/incongruent trials. Half of the participants received a test series with more congruent than incongruent trials, whereas the remaining participants received more incongruent than congruent trials. The hypothesis was that in the mainly incongruent condition, the participants had to use a color naming strategy while inhibiting automatic word reading for successful performance. In the mainly congruent condition, by contrast, participants could choose either a color naming or word reading strategy and still do relatively well. If, according to the inhibition theory, inhibitory processes in older adults are deficient, it was expected that this age group would show more interference in the mainly incongruent condition. In contrast, no age differences were expected in the congruent condition, because the task allowed for the use of a word reading strategy, which the older adults could use to achieve the correct response. Results showed that older adults exhibited more interference in the incongruent as opposed to the congruent condition when compared to younger adults. These age differences were maintained even after performance responding rate was covaried out. From the results, the authors concluded that the contributions of processing speed and inhibition to successful performance varied according to the requirements of the task.

These results highlight a need to investigate the relationship of both processing speed and inhibitory functioning to age-related cognitive deficits in working memory. In a review of the literature on processing speed, Salthouse (1996) himself has stated that the postulation of a generalized slowing mechanism does not preclude the possibility of additional specific processes that are also affected with age.

The aim of study two was to investigate the potential contribution of processing speed to performance in the inhibition condition of the VRWM task. The inhibition theory states that the inability to suppress irrelevant material in working memory can lead to interference from this distracting information. The goal of the study was to change the task demands of the VRWM by changing the type of stimuli used, with the intention of increasing the amount of interference assumed to occur within the task and thus the need for inhibitory processes. Age differences in performance were expected to increase as the amount of interference increased. In contrast, the processing speed theory would predict equal age differences regardless of the type of material to be processed, so long as the task parameters themselves did not change.

In an attempt to increase interference effects, stimuli for the item recognition task were chosen based on category membership. Words from the same category are thought to have stronger associative bonds than unrelated words, which in theory may be more difficult to suppress, therefore causing greater interference effects. It has been demonstrated in a variety of tasks that words from the same category can cause greater proactive interference effects than words from different categories. For instance, the classic proactive interference in short term memory paradigm (Wickens, 1972; Wixted & Rohrer, 1993) has demonstrated a decrease in free recall performance across trials when the stimuli used are words from the same category, presumably due to a build-up in proactive interference. This is followed by a return to the original level of performance when the category is changed.

As discussed earlier, inefficient inhibitory processes will result in increased interference effects as reflected in lowered accuracy and slower response times. Given that the inhibitory mechanisms are deficient with age, irrelevant material will remain activated in working memory. The use of a categorized word list is expected to increase the amount of interference that is experienced because of this sustained activation across a pair of trials, involving the same category in comparison to an unrelated list. Thus, age differences in the recent negative condition should be greater in the categorized list presentation.

Although the inhibition theory does predict a different pattern of results with the two word list conditions, the processing speed theory would not necessarily predict a difference in the proportion of age-related variance accounted for by perceptual speed. Because the task is identical in both list conditions, with the exception of the stimuli used, the processing speed theory would assume that the underlying processes are the same in both conditions. The use of different stimuli should not affect these processes; therefore the processing speed theory would not predict age-related differences in performance across the two word lists.

To examine more specifically the relationship between processing speed and inhibition with age, a hierarchical regression analysis was used (Hertzog, 1996; Salthouse 1991; 1994). If speed mediates the declines in working memory that accompany age, then controlling for speed, the proportion of age-related variance in working memory performance should be substantially reduced. Processing speed was assessed using two perceptual speed measures, often used in studies investigating cognitive slowing and age (Salthouse, 1996). These were the pattern comparison and the letter comparison tasks. Following the evidence reviewed earlier, it was expected that both processing speed and inhibitory functioning would affect performance in the older age group. It was expected that the perceptual speed measures may mediate some of the age-related variance on the item recognition task, but not all because of the hypothesized role of inhibition in this task. The processing speed theory would predict that the proportion of age-related variance accounted for by the perceptual speed measures would be roughly equivalent for the two list types. In contrast, the inhibition view would predict that inhibitory processes differentially come into play for each word list condition, with inhibition being a more important factor as the amount of interference increases. In particular, although speed is expected to account for a significant proportion of the age-related variance in item-recognition performance, there would still be a significant amount of variance still unaccounted for, which it is argued is a reflection of inhibitory processes. However, there will be a weaker, non-significant relationship between the speed measures and performance in the increased interference condition, presumably because it is the added deficit of inhibition that accounts for the additional age-related decline in performance.

In addition, although secondary to the aim of the study, not only was the category manipulation expected to increase interference effects, it was also thought that the use of categorized lists would increase facilitation effects across a pair of trials. The stronger associative connections of words from the same category would more likely maintain activation of the item in the recent positive condition, thus leading to greater facilitatory effects with the categorized list. However, it is uncertain whether there should be age differences in the amount of facilitation evidenced in the recent positive condition as compared to the positive condition. Therefore, it was predicted that both the recent negative and recent positive conditions would show increased effects overall, while performance in the positive and negative conditions should be better in the categorized list.

METHOD

Participants

One hundred adults divided into five equal age groups (18-29; 30-44; 45-59; 60-74; 75 years and older) were tested. The young adults were undergraduate students who received course credit for their participation. The remaining adults were recruited from the local community and were paid ten dollars for their participation. Exclusion criteria were the same as in Study 1. Two participants were excluded based on a diagnosis of bipolar disorder and were taking Lithium (one adult from the 18-29 range and one from the 46-59 range). Two additional adults were tested to maintain equal sample sizes.

Descriptive data are presented in Table 6. One-way analyses revealed significant differences in level of education (F (4,95) = 2.73, MSe = 4.19) and Shipley scores (F (4,95) = 16.05, MSe = 13.38) between the five age groups. Post hoc comparisons for education showed that the 60-74 year olds had obtained a significantly higher level of education than the other four age groups. No other differences were significant. Post hoc analysis for the Shipley scores revealed that the two youngest groups had significantly lower vocabulary scores than the three older groups, and were significantly different from each other.

Presence of depressive symptoms was assessed as in Study 1 using the Beck Depression Inventory for the three youngest groups and the Geriatric Depression Scale for the two older groups. Mean scores on the self-report questionnaires were 6.1 (S.D. = 6.49) for the 18-29 year olds, 4.6 (S.D. = 3.3) for the 30-44 year olds, 5.55 (S.D. = 5.38) for the 45-59 year olds, 4.35 (S.D. = 3.3) for the 60-74 year olds and 4.05 (S.D. = 1.7) for the 75 and older group. Using a cut-off of 10, 4 individuals from the 18-29 group, 2 from the 30-44 and 2 from the 45-59 group scored above the cut-off value. Analyses were conducted both with and without these individuals with similar results. As a result these data were retained in the following analyses to maintain equal sample sizes and greater power.

Verbal Item Recognition test

Materials

Two lists were developed for this study. The structure of the lists was the same as in Study 1, with 20 trials in each of the four conditions (i.e. positive, facilitation, negative and recent negative). The first list consisted of nouns of varying length again chosen from the Kuchera and Francis (1967) frequency norms with a range of 4 to 450, referred to as the unrelated list. Although the basic list of items was essentially the same as that of Study 1, some of the words were replaced with longer words in an attempt to equate for word length between list conditions. A second list of items was developed that used nouns chosen from the Battig and Montague (1969) category norms. Words were chosen from 40 separate categories with the constraint that there were enough category instances that were less or equal to 8 letters in length to fulfill the necessary conditions. The most representative members of each category were chosen. Each array of words consisted of four items from the same category; on each trial the array had words from a different category unless it was in a facilitation or recent negative condition, for which the category remained the same. Four separate lists for the unrelated and categorized lists were designed to counterbalance the position of each array in each of the four conditions.

Procedure

The procedure was similar to Study 1. Each participant completed both the unrelated and the categorized conditions. Administration of the two list types was counterbalanced. The perceptual speed measures were completed between the administration of the two list types. Shipley scores were also obtained for each individual.

Perceptual Speed Measures (Salthouse, 1994)

Two paper and pencil measures of processing speed were administered: the letter comparison and the pattern comparison task. The letter comparison task consisted of pairs of three, six, or nine letters presented on a page. The participant was asked to respond as quickly as possible with an S if the pairs were the same or D if they were different. Thirty seconds was allotted for this task, and the score was computed as the number correct minus the incorrect responses. The procedure of the pattern comparison task was equivalent to the letter comparison task except that the stimuli consisted of pairs of patterns with three, six, or nine line segments. Two trials of each the letter and pattern comparison tasks were administered and an average score was computed separately for both speed measures.

RESULTS

The raw data for the response time and accuracy score across the five age groups are shown in Tables 7 and 8 for the unrelated and categorized lists respectively. The response time data were first trimmed to remove outlying responses that were more than 3 standard deviations from the mean. Just as in Study 1, the amount of data lost to this procedure was minimal. For the unrelated condition, the percent of data lost across the five age groups (beginning with the youngest age range) were 0.96, 1.05. 1.50, 1.3, and 1.16. A one-way ANOVA failed to find any differences in lost data between the age groups. A similar pattern of results was obtained for the categorized condition, with again no age differences noted. Percent data removed for the five age ranges, starting with the youngest in order, were 0.84, 1.80, 1.76, 1.62, and 1.88.

An age (5) X list type (2) X condition (4) was conducted first for the accuracy data. A main effect for condition ($F(3,285) = 23.42$, $MSe = 49.20$, $eta^2 = 0.20$) and age ($F(4,95) = 3.91$, $MSe = 130.19$, $eta^2 = 0.14$) were found. In addition, the condition X age interaction was significant ($F(12,285) = 3.2$, $MSe = 49.20$, $eta^2 = 0.12$) as was list X condition ($F(4,285) = 1.36$, $MSe = 29.08$, $eta^2 = 0.04$).

The parallel analysis for the response time data showed a main effect for condition ($F(3,285) = 64.60$, $MSe = 16087.31$, $eta^2 = 0.41$), and age ($F(4,95) = 10.38$, $MSe = 188521.85$, $eta^2 = 0.30$) as well as a list by condition interaction ($F(43285) = 3.85$, $MSe = 4626.47$, $eta^2 = 0.04$). Since the comparisons of interest were between the inhibition and facilitation conditions, separate analyses were done for each, with a goal to understanding the interactions.

Inhibition Comparison

Age X list (categorized vs. unrelated) X condition (recent negative vs. negative) analyses were conducted to test for the expected increased interference in the categorized condition. For the accuracy data neither the main effect of list type nor any of the interactions with list type were significant. Contrary to expectations, the recent negative condition did not show larger age effects for the categorized vs. the unrelated lists. A main effect of condition ($F(1,95) = 57.47$, $MSe = 47.23$, $eta^2 = 0.38$) and age were found ($F(4,95) = 4.82$, $MSe = 112.39$, $eta^2 = 0.17$) as well as a condition X age ($F(4,95) = 6.97$, $MSe = 47.23$, $eta^2 = 0.23$) effect shown in Figure 3. In particular for the first four age groups little interference effects were noted as evidenced by a lack of difference between accuracy in the recent negative and negative conditions. In contrast, the oldest age group showed a decrease in accuracy in the recent negative condition compared to the negative condition, suggesting increased interference effects restricted to the oldest age group.

The response time data showed a main effect of age ($F(4,95) = 9.06$, $MSe = 135501.07$, $eta^2 = 0.27$) and condition ($F(1,95) = 170.33$, $MSe = 13431.04$, $eta^2 = 0.64$). In addition the list X condition ($F(1,95) = 5.08$, $MSe = 4522.63$, $eta^2 = 0.05$) and the 3 way interaction were significant ($F(4,95) = 2.54$, $MSe = 4522.63$, $eta^2 = 0.10$). The 3-way interaction is plotted in Figure 4. The significant interaction seems to reflect some slight reversals across age in the relative response times in the categorized vs. unrelated recent negative conditions. Although statistically significant, this interaction was not predicted by the study and the pattern does not appear to be theoretically significant. Of importance to this study, there was a trend for the age X condition interaction; however it did not reach significance ($p \leq .13$, $eta^2 = 0.07$). When vocabulary skill was used as a covariate in the analyses, results were similar except that there was only a trend for the 3-way interaction to be significant.

Taken together, results from the accuracy and response time data are consistent with the idea that compared to younger adults the older adults have more difficulty suppressing information from earlier trials, leading to increased interference in the recent negative condition as demonstrated by reduced accuracy and slower response times. However, this was only a trend in the response time data. To increase the power of finding possible age differences, the data from this study was joined with the data from Study 1. The data from the youngest age group and the two oldest age groups were collapsed for the unrelated list condition. Participants were chosen from the same age range in both studies allowing for a combination of the two data sets. This procedure allowed for an increase in the sample size to 40 young and 80 old adults. An age (young vs. old) X condition (recent negative vs. negative) X study (study one vs. study 2) analysis was performed. The accuracy data showed significant main effects of age and condition but no differences between Study 1 and Study 2. In addition, the age X condition interaction reached significance ($F(1,116) = 8.86$, $MSe = 50.84$, $eta^2 = 0.07$), with the older adults' performance in the recent negative condition declining relative to the young adults (Figure 5). Response time analyses demonstrated the same pattern of results. Both the main effects of age and condition were significant as was the age X condition interaction (Figure 6; $F(1,116) = 10.83$, $MSe = 7957.96$, $eta^2 = 0.09$). The older adults had relatively more difficulty in the recent negative condition than the young as evidenced in their slower response times than in the negative condition. A similar pattern of results was found using vocabulary as a covariate in the analyses.

Facilitation Comparison

An age X list type by condition (recent positive vs. positive) analysis was conducted first for the accuracy data. Results showed an effect of list type ($F(1,95) = 5.64$, $MSe = 29.91$, $eta^2 = 0.06$) and condition ($F(1,95) = 15.11$, $MSe = 25.94$, $eta^2 = 0.14$). In addition the list X condition comparison was significant ($F(1,95) = 4.19$, $MSe = 28.90$, $eta^2 = 0.04$) showing that overall facilitation effects were demonstrated in the categorized list but not the unrelated list. The age X list interaction approached significance ($p \leq .06$, $eta^2 = 0.08$, power = 0.63) showing a trend for the two oldest groups to show lowered performance in the categorized list condition, unlike their younger counterparts who did not show a change in accuracy.

A similar analysis was conducted with the response time data. A main effect of list ($F(1,95) = 4.41$, $MSe = 12908.51$, $eta^2 = 0.04$) was found with overall slower response times demonstrated in the categorized list. There was also a main effect of condition ($F(1,95) = 16.76$, $MSe = 3907.07$, $eta^2 = 0.15$) with faster response times evidenced in the recent positive condition. In addition response times increased with age (18-29 yr. olds M = 685.14; 30-44 yr. olds M = 778.2; 45-59 yr. olds M =744.92; 60-74 yr. olds M = 889.12; 75+ yr. olds M = 924.77; ($F(4,95) = 9.56$, $MSe = 83944.64$, $eta^2 = 0.29$).

Processing Speed

Raw data for the processing speed measures are shown in Table 9. One way ANOVAs were performed for the letter and pattern comparison speed measure separately. In both cases, there was a significant age effect, with the older adults obtaining lower scores on these measures (Letter Comparison $F(4,95) = 12.56$, $MSe = 5.23$; Pattern Comparison $F(4,95) = 24.20$, $MSe = 8.13$) To evaluate the contribution of processing speed to item recognition performance, the aim was to run hierarchical regression analyses, by first looking at the amount of age-related variance and then by evaluating the proportion of this variance that remained once the effects of processing speed were partialled out. However, the relative role of processing speed in the interference effects of the item recognition test cannot be fully tested as hypothesized because the manipulation designed to increase interference effects failed. Nonetheless, there were significant correlations between age and the accuracy and response time data in the recent negative condition, so the relative contribution of processing speed to this relationship was examined. First, because no differences were found between the categorized and unrelated lists, data were collapsed across the two list conditions. As a measure of interference, difference scores were calculated by subtracting the negative condition from the recent negative condition for both the accuracy and response time data. This difference was thought to reflect the increased interference effects in the recent negative condition. A significant relationship was found between age and the accuracy difference score (r = 0.36) as well as age and the response time difference score (r = 0.23).

To collapse data from the letter and pattern comparison measures, z-scores were first computed for each measure and then averaged together to arrive at one composite speed measure which was then used in the regression analyses.

A hierarchical regression analysis was performed on accuracy and response time separately. Vocabulary skill was used as a covariate in the analyses. Because of the strong correlation between age and vocabulary, age was first regressed onto vocabulary scores and the unstandardized residuals were saved. These unstandardized residuals were then covaried out by entering them into the equation first. Table 10 demonstrates the order of entry into the regression model. Age accounted for a significant proportion of the variance in accuracy performance in the recent negative condition. However, when processing speed was entered into the equation, age no longer accounted for a significant proportion of the variance for accuracy performance. Similar results were found for the response time data.

DISCUSSION

The results from this study did not support the expectation of overall increased interference effects in the categorized list condition as compared to the unrelated list. Nor did they show a differential increase in interference effects associated with age, as predicted by the inhibition theory of aging. In an attempt to understand these contrary findings, we need to look more closely at the manipulation used in this study so that we can say whether it increased interference. The categorized words were presented in blocks, i.e. each array of fours words was from one category with items in the next array from a different category unless it was the facilitation or interference condition, where it was necessary to continue with the same category. On further consideration, this use of the blocking procedure may actually parallel more closely a release from proactive interference experiment, one in which less, rather than more, interference would be expected. It has been shown that although one sees declining recall performance over trials when words from the same category are used, recall rates rebound when the next presentation uses stimuli from another category; i.e. release from proactive interference (Wickens, 1972; Wixted & Rohrer, 1993). Thus, in this study although interference may have built up across a few trials due to inefficient inhibitory mechanisms, each time the category shifted it can be argued that this manipulation most likely "released" any buildup of proactive interference so that an increase in interference effects in the categorized list condition would not be expected. Therefore, unfortunately, the very manipulation intended to increase interference effects may have worked contrary to the original plan and produced the reverse. Given this line of reasoning, these results imply that there may have been an overall increase in proactive interference in the item recognition task across all of the trials that may have been contributing to age differences, rather than just an increase within a given pair of trials in the recent negative condition.

Nonetheless, consistent with results of Study 1, the oldest age group demonstrated increased interference effects on the item recognition task (regardless of list type) compared to the other age groups, presumably due to decreased inhibitory functioning. Even stronger support for the view of age related declines in inhibition were found when the unrelated list condition data from participants chosen from the same age brackets were combined with data from the first study. In particular, the hypothesized age differences in performance in the interference condition were evident. Specifically, the older individuals showed a differential decline in performance in the recent negative as opposed to the negative condition. This pattern of results suggests that material from earlier trials remains activated in working memory longer in older adults, due to inefficient inhibitory mechanisms that would otherwise suppress or delete no longer relevant information so that it does not interfere with subsequent processing. As a result of the maintenance of information in working memory from earlier trials, when the probe item actually matches one from an earlier list, it becomes relatively more difficult for older adults to respond appropriately because a match is found in working memory, albeit not the correct match, leading older adults to make more errors as evidenced in decreased accuracy and slower response times.

The category manipulation, on the other hand, did work in increasing overall facilitation effects. Seeing a word presented on two successive trials produced better performance when presented within a categorized structure. The strong associative links between members of a common category most likely aided in maintaining activation of the word across trials. In addition, when trials were presented in succession with stimuli from the same category, this method of blocking may have alerted participants more to consistencies between trials, and highlighting the fact that when a word was repeated across trials, it would also be the probe target.

One further point, it is unclear why only the very oldest age group would demonstrate increased interference effects whereas the 60-74 year olds failed to show this effect. Results of Study 1 failed to find differences between a group of young-old and old-old individuals in either the n-back or the item recognition task. It is unclear why only the oldest group, similar in age to the old-old in Study 1, would show a interference effects, whereas the next youngest group, chosen from the same age range as the young-old of Study 1, would show a more similar pattern of performance in the interference comparison to their younger counterparts. It may be that there were differences in sample characteristics or individual differences between the groups of participants, even though the average age and education level and vocabulary skill of each group were very similar. Unfortunately, the Mini Mental State Examination was not administered to the older subjects in study 2, so it is possible that some of the oldest subjects were mildly cognitively impaired. If so, that would skew the results in the direction of age differences when in reality no differences are present. However, it is still important to stress that when the data were combined across studies, thus increasing the power of the analyses, a reliable age difference was evident in the inhibition condition.

GENERAL DISCUSSION

The aim of the current studies was to evaluate the role of inhibitory processes in working memory performance differences associated with advancing age. Given the view that inhibitory mechanisms become less efficient with age, decreased performance on two measures of working memory, the n-back and the item recognition tasks, was expected. Overall, the results supported the premise that inefficient inhibitory mechanisms account, at least in part, for age-related decrements on working memory tasks. This was most clearly seen in results with the n-back task. As task complexity increased in the 2-back condition, requiring the processing of relatively more information than in the 1-back condition, older adults showed greater difficulty as evidenced in decreased accuracy and slower response times.

In addition, the examination of performance on specific foil trials in the n-back task provided stronger support for the inhibition viewpoint. The inclusion of the critical 3-back condition provided additional evidence for decreased inhibitory functioning associated with age. As originally hypothesized, if older adults have more difficulty deleting information from working memory, this could lead to increased interference effects due to an increase in "clutter". In the n-back task, with the continual need to update the contents of working memory as each new letter is presented, it was hypothesized that for the older adults, letters presented earlier in the sequence would remain activated in working memory, thus making it more difficult for the older adults to successfully complete the task because of a resulting increase in interference effects. To test this hypothesis on some trials the probe item actually matched an item that was in the 3-back position rather than the 2-back item. Although the appropriate response would be "no" (i.e. it does not match the letter in the 2-back position), it was hypothesized that older adults would experience more difficulty on these trials presumably because the 3-back item was still activated in working memory. Results from Study 1 supported this hypothesis. Although overall, all participants had more difficulty when the target letter actually matched the 3-back item, the difficulty for older adults was greater, based on response time and accuracy measures, than their younger counterparts.

Although the age effects were not significant in the item recognition task in Study 1, there was a trend toward increased interference effects with advancing age. Furthermore, when comparable data from both Study 1 and 2 were combined, increasing the overall sample size and thus the power of the analyses, the age X condition interactions were significant, indicating that compared to the younger adults older adults showed larger interference effects in the recent negative condition than the negative condition. The larger age effects in interference are consistent with the view that inhibitory functioning decreases with age.

Taken together, these results suggest that in older adults inhibitory functioning becomes less efficient leading to decrements in performance in working memory tasks. This inefficiency allows irrelevant information to remain activated in working memory, leading to decreased performance due to interference that is caused by this extra information.

Role of the Prefrontal Cortex and Inhibition

Results from Study 1 provided indirect evidence for the role of the prefrontal cortex in inhibition. A significant relationship was found between performance on the WCST and the n-back task. In particular, this relationship was only significant for the 2-

back version, the one in which clear age differences were found. This result supports other studies that have reported links between frontal lobe functioning and inhibitory deficits (Chao & Knight, 1997; Cronin-Golomb, 1990; Stuss & Benson, 1984). However, it is important to note that WCST is a complex neuropsychological measure, one that cannot be easily classified as a specific measure of any one cognitive process, such as inhibition. In fact the primary role of the prefrontal cortex in performance on the WCST has been questioned (Anderson, Damasio, Jones, & Tranel, 1991) with additional cortical and/or subcortical areas implicated. Additional studies are necessary to more fully examine the possible link between specific neuroanatomical areas and inhibitory functioning. The use of neuroimaging procedures could provide useful information in this regard.

There is strong evidence in young adults that the prefrontal cortex is important for working memory and, specifically for the n-back task. Using positron emission tomography (PET) (Schumacher, Lauber, Awh, Jonides, Smith & Koeppe, 1996), in comparison to a control condition (in this case a 0-back condition), the verbal n-back task showed increased activation in Broca's area, the left posterior parietal lobule and to a lesser degree the right posterior parietal and supramarginal area (Brodmann's area 40), as well as the left dorsal lateral prefrontal cortex (DLPFC, Brodmann's area 9, 10, 44, 45, 46). The same pattern was evidenced for a spatial version of the n-back task in the homologous regions in the right hemisphere. These results replicate earlier findings that have implicated these brain areas in working memory. This verbal working memory system appeared to be amodal, in that these same areas were activated whether the stimuli were presented visually or auditorily. To understand more fully the role of the different brain regions in working memory, Awh and colleagues (Awh, Jonides, Smith, Schumacher, Koeppe, & Katz, 1996) used a 2-back task to study the relative contributions of these areas to storage and rehearsal processes. Results suggested that Broca's area and surrounding speech areas were important in rehearsal, whereas the posterior parietal and DLPFC appeared to be involved in storage of information in working memory. Using a time series design, Cohen and colleagues (Cohen, Perlstein, Braver, Noll, Jonides, & Smith, 1997) also demonstrated putatively different roles for the various cortical areas that are activated in the n-back task. Early in the task, Broca's area showed increased activation as the memory demands increased presumably due to rehearsal processes, but this activation actually decreased over the time delay. The posterior parietal areas showed increasing activation with increased memory load that was sustained across the delay, supporting its role in the storage of information. Interestingly the DLPFC did not show increased activation for the 0 and 1-back conditions but did show a marked increase during the 2 and 3-back trials that was sustained over the delay. These results suggest that the DLPFC may play a role in more complex working memory tasks.

Parametric studies also have been used to investigate the relationship between neuroanatomical regions and working memory (as opposed to the subtraction method that was used in the studies described above). The following studies dealt only with the verbal n-back procedure. Jonides et al. (1998), using four lag conditions (0,1,2 and 3), found activations in the same areas as described earlier that increased linearly with increasing memory load. Braver et al. (Braver, Cohen, Jonides, Smith, & Noll, 1997) replicated these findings using fMRI instead of PET.

The use of neuroimaging data to examine the age deficits observed on the n-back task could prove fruitful. Data from neuroimaging research could provide additional evidence in support of the role of the prefrontal cortex to inhibition. In particular it would be interesting to examine the amount of activation that occurs in the prefrontal cortex when directly comparing the recent negative and negative conditions in this task. If the PFC subserves inhibitory processes, then it would be expected that one would see a difference in activation rates in this area in the recent negative condition as compared to the negative condition. Furthermore, given that the older adults in this study showed inefficient inhibitory functioning compared to young adults on the n-back task, one possible outcome would be that the results of the neuroimaging data would parallel the behavioral outcome, demonstrating a relative decrease (or increase) in activation in the PFC for the inhibition (i.e. recent negative) condition in comparison to the young adults.

Jonides et al (2000; Jonides et al., 1998) did find results that support this hypothesis using the item recognition task. In particular not only did they find that the older adults had more difficulty behaviorally in the recent negative condition compared to young individuals, they also found that there was no reliable activation of the PFC in the older adults during these trials, unlike the increase in PFC activation seen with the young individuals.

Inhibition and Processing Speed

Unfortunately, because Study 2 was not successful in increasing interference, the relative roles of processing speed and inhibition could not be examined across different tasks that presumably relied differentially on inhibitory mechanisms for successful performance. Nonetheless, processing speed measures did account for almost all of the age-related variance demonstrated in performance in the item recognition task. These results suggest that at least in the item recognition task, most of the age effects seen in study 2 were mediated by processing speed. However, it is important to note two points. First, the age related declines in performance in the inhibition condition in the item recognition task were relatively weak. Clear age declines in performance were not evident until the sample size was greatly increased by collapsing data across the two studies. As a result, it is unclear at this stage if the processing speed results refute the inhibition hypothesis of aging, or if the declines in performance due to inhibition deficits are relatively small, thus making it difficult to partition the contribution of different processes to this task.

Second, recent research has called into question the validity of the perceptual speed measures as good measures of information processing speed (Lustig et al., 2000; Tonev et al., 2000). As suggested by these researchers, if interference effects account, in part, for the age differences in the perceptual speed measures, then it is not surprising that covarying out these measures from the regression analyses would account for much of the age-related variance in performance. Given this argument, the present findings then are not inconsistent with the inhibition view of aging; however, further research is needed to examine this issue. In particular, using a perceptual speed measure that presents items one at a time, thereby reducing visual distraction, may provide very different results.

<u>Relationship between inhibitory processes and age within the older age spectrum</u>

Contrary to expectations, generally no age differences were observed between the two oldest age groups in the n-back and item recognition task (except for increased interference effects in adults over the age of 75 in the categorized list condition of study 2). These results are not consistent with the bulk of literature that has demonstrated continued cognitive declines with advancing age (Christensen et al., 1994; Osterweil et al., 1994) including continued declines in inhibitory functioning (Persad et al., in press but see Speiler, Balota, & Faust, 1996). Given that age differences on other standardized measures were obtained (i.e. WCST, perceptual speed measures) consistent with the aging literature, it is difficult to account for this finding. As already noted, characteristics of the older adults in this study may have contributed to the lack of differences; in particular the older individuals used in this study were generally highly educated and may not be a representative sample of the older population. In comparison, the older adults tested in the Persad et al. study (in press) were recruited actively from the local community and on average had lower education levels and thus may have been more representative of the general older population (Mean education for adults over the age of 75 in Study 1 =15.3, Study 2 = 14.3, Persad et al. study = 12.6). Further research is needed to determine whether inhibition does continue to decline with advancing age.

FUTURE DIRECTIONS

A number of relatively simple studies can be designed using minor alterations to the tasks employed in these studies to further examine inhibition and its role in age-related decrements in working memory. Since the original aim of Study 2 was to increase interference effects and hence the need for inhibition to successful performance, a first goal would be to re-run Study 2 using a word list that was properly designed to increase interference effects. Simply making some minor alterations to the categorized list condition could do this. Basically, the same stimuli and procedure could be used; however, the format of the categorized list would need to be revised. In particular the use of words from a limited number of categories that repeat throughout the list, as opposed to the use of a blocking procedure, could achieve the desired affect. This format should eliminate the "release from proactive interference" design allowing for a presumed build-up in interference effects due to the strong pre-existing associative bonds that have been hypothesized to exist for categorized words.

A more fruitful line of research would probably make use of the n-back task because reliable age differences were found with this measure. In addition to needing to replicate the age findings, the stimuli could also be designed to increase interference without changing the underlying task procedure. In this study, it was stipulated that no letter was repeated within a series (unless part of a positive or recent negative trial). Increasing the number of times a letter was presented in a list should lead to increased interference effects; however it would be important to try to distinguish age effects from other age-related changes such as diminished capacity for recalling the temporal order of items (Kausler, Salthouse, & Saults, 1988). This task could also prove especially useful for examining the relative roles of processing speed and inhibition because of the clear evidence for age differences in performance. In addition, as stated above, further study with neuroimaging techniques to look at underlying neuroanatomical systems that are involved in age-related declines in inhibition could prove to be very interesting.

Working Memory Subsystems and Inhibition

The present study focused on age differences in two working memory measures, the n-back and the item recognition task, both presumed to rely on verbal working memory processes. Yet, findings from both the neurocognitive and neuroimaging literature suggest the presence of three separate subsystems in working memory, each of which deals with a different type of stimuli, and each of which is subserved by a different region of the brain. In particular, these three subsystems have been referred to as verbal, spatial, and object working memory. The verbal working memory system, as described earlier, comprises Baddeley's original conception of a phonological loop (Baddeley, 1992; Baddeley, & Hitch, 1994). However, the original conception of the visual-spatial sketchpad has been further divided into a system that is involved in the spatial aspects of stimuli, such as location or orientation in space, versus the identification of an actual visual object.

As discussed earlier, some researchers have suggested that there are multiple inhibitory mechanisms, only some of which are affected with age. Different suggestions have been made, however, about the particular mechanisms associated with age changes. For example, Carlson et al. have hypothesized that there is an inhibitory mechanism that deals with spatial location, and that it is this mechanism that is age invariant (Carlson, Hasher, Connelly & Zacks, 1995). This inhibitory mechanism also has been linked to the occipitoparietal or dorsal neural pathway, which has been linked to the processing of location. By contrast, age declines in inhibition associated with indentification of stimuli are thought to be related to the ventral pathway. Kramer and colleagues (1994) also hypothesized multiple inhibitory mechanisms, but have proposed that only those that rely on frontal lobe functioning are affected by age. On the premise that there are multiple inhibitory pathways and that only some are affected by age, it would be interesting to design studies to look at age-related inhibitory functioning in the three separate working memory subsystems. A first general question is to examine whether there is a global decline associated with inhibition that cuts across all working memory systems or whether there are more specific age changes that are dependent both on the task processes and the type of stimuli used.

In summary, the results from both studies presented in this paper provided evidence of increased interference effects with age that are consistent with the viewpoint that inhibitory mechanisms become less efficient with age, leading to reduced performance on working memory tasks.

FOOTNOTES

1. Due to the design of the n-back task a trimming procedure was not necessary. In the n-back task stimuli were continually presented at a rate of one every 3 seconds in total and a response had to be made within this time frame or else it was considered an error. This is in comparison to the item recognition task where the next trial was presented only after a response was made by the participant.

2. Although vocabulary skill was not expected to influence performance as much in the n-back task, a possible relationship vocabulary skill and n-back performance was examined; however, none of the correlations between the Shipley vocabulary score and any of the n-back scores were significant.

APPENDIX

APPENDIX

Table 1. Age, Education and Vocabulary scores for the three age groups.

	N	Age Mean (SD)	Education Mean (SD)	Shipley Vocabulary Mean (SD)
Young	20 (3M, 17F)	**19.35** (1.23)	**13.05** (1.19)	**30.16** (3.23)
Young-Old	20 (9M, 11F)	**69.40** (4.03)	**14.00** (2.45)	**32.40** (5.59)
Old-Old	20 (9M, 11F)	**78.10** (2.51)	**15.30** (3.11)	**36.15** (3.13)

APPENDIX

Table 2. Accuracy and Response time data in the 1-back condition for the three age groups in Study 1.

	Percent Accuracy Mean (SD)			Response Time (msec) Mean (SD)		
Age	Positive[a]	Negative[b]	Recent Negative[c]	Positive	Negative	Recent Negative
Young	**93.50** (5.81)	**99.82** (0.37)	**97.32** (2.80)	**530.06** (57.52)	**512.73** (65.99)	**613.48** (79.80)
Young-Old	**92.33** (6.50)	**99.44** (0.64)	**92.17** (10.72)	**638.33** (110.12)	**628.67** (107.64)	**733.04** (125.03)
Old-Old	**89.35** (8.85)	**99.48** (0.92)	**95.24** (8.23)	**620.49** (110.96)	**613.77** (77.38)	**733.04** (125.03)

[a] Positive: probe item matches the item 1-back in the sequence
[b] Negative: probe item does not match the item 1-back
[c] Recent Negative: probe item matches the item 2-back in the sequence

APPENDIX

Table 3. Accuracy and Response time data in the 2-back condition for the three age groups.

	Percent Accuracy **Mean** (SD)				Response Time (msec) **Mean** (SD)			
Age	Positive[a]	Negative[b]	Recent Negative[c]	1-Back	Positive	Negative	Recent Negative	1-Back
Young	**87.24** (7.0)	**99.32** (1.08)	**75.29** (18.44)	**89.00** (16.19)	**663.25** (162.19)	**658.27** (169.25)	**770.79** (239.94)	**837.53** (243.78)
Young-Old	**76.97** (10.14)	**97.97** (3.62)	**62.63** (19.24)	**71.93** (22.31)	**794.00** (165.22)	**790.95** (151.6)	**965.83** (180.03)	**1125.85** (223.52)
Old-Old	**77.34** (11.44)	**98.06** (3.03)	**60.74** (18.66)	**71.99** (20.56)	**782.70** (175.74)	**760.24** (132.06)	**920.55** (201.93)	**1093.79** (243.98)

[a] Positive: probe item matches the item 2-back in the sequence
[b] Negative: probe item does not match the item 2-back
[c] Recent Negative: probe item matches the item 3-back in the sequence

APPENDIX

Table 4. Accuracy and Response time data from the Item Recognition test across the three age groups.

	Percent Accuracy **Mean** (SD)				Response Time (msec) **Mean** (SD)			
Age	Positive [a]	Facilitation [b]	Negative [c]	Recent Negative [d]	Positive	Facilitation	Negativ e	Recent Negative
Young	**94.75** (5.73)	**95.25** (5.5)	**98.75** (2.22)	**92.75** (4.44)	**699.60** (169.5)	**673.67** (156.72)	**683.67** (152.43)	**803.00** (166.92)
Young -Old	**88.89** (15.2)	**91.11** (9.79)	**98.06** (4.89)	**87.78** (8.08)	**932.49** (146.04)	**923.06** (131.75)	**874.32** (143.08)	**1085.09** (235.33)
Old-Old	**91.58** (10.42)	**95.79** (6.72)	**97.37** (5.86)	**87.37** (12.95)	**882.51** (153.19)	**860.08** (160.58)	874.36 (130.94)	**1044.82** (175.0)

[a] Positive: Probe item is a member of the target array
[b] Facilitation: Probe item is a member of the target array and the previous array
[c] Negative: Probe item is not a member of the target array
[d] Recent Negative: Probe item is not a member of the target array but was a member of the previous array

APPENDIX

Table 5. Means and Standard deviations for WCST variables for the three age groups.

Age	Number Correct	Perseverative Responses	# of Categories
Young	**70.40** (6.98)	**16.06** (10.89)	**5.35** (1.27)
Young-Old	**73.84** (10.74)	**17.40** (9.68)	**5.00** (1.45)
Old-Old	**66.84** (16.80)	**30.23** (28.21) [a]	**3.32** (2.36) [a, b]

[a] old-old group is significantly different than the young group.

[b] old-old group is significantly different than the young-old group.

APPENDIX

Table 6. Age, Education and Vocabulary scores for the five age groups in Study 2.

Age	N	Age Mean (SD)	Education Mean (SD)	Shipley Vocabulary Mean (SD)
18-29	20 (9M, 11F)	**20.30** (2.58)	**13.1** (1.37)	**28.06** (4.01)
30-44	20 (9M, 11F)	**36.45** (3.76)	**14.3** (1.78)	**31.75** (4.58)
45-59	20 (6M, 14F)	**51.60** (4.33)	**14.5** (2.48)	**35.00** (3.49)
60-74	20 (12M, 8F)	**69.55** (4.07)	**15.2** (2.46)	**35.12** (3.15)
75+	20 (6M, 14F)	**79.05** (3.56)	**14.3** (1.92)	**35.94** (2.78)

APPENDIX

Table 7. Study 2 Accuracy data from the Unrelated and Categorized Item Recognition test across the five age groups.

	Percent Accuracy Unrelated List **Mean** (SD)				Percent Accuracy Categorized List **Mean** (SD)			
Age	Positive[a]	Facilitation[b]	Negative[c]	Recent Negative[d]	Positive	Facilitation	Negative	Recent Negative
18-29	**93.57** (5.30)	**95.72** (4.95)	**97.75** (3.02)	**96.25** (5.35)	**93.17** (6.68)	**96.25** (7.93)	**99.53** (1.46)	**97.50** (3.03)
30-44	**94.50** (6.05)	**93.50** (9.88)	**97.25** (3.8)	**93.75** (7.23)	**92.50** (6.79)	**92.25** (7.86)	**98.50** (5.64)	**93.25** (10.55)
45-59	**95.50** (4.26)	**96.50** (4.32)	**98.00** (3.4)	**96.50** (5.40)	**93.99** (6.8)	**97.25** (3.02)	**99.00** (2.62)	**95.25** (6.78)
60-74	**96.00** (5.76)	**95.75** (6.13)	**98.00** (4.1)	**92.25** (8.03)	**88.75** (10.11)	**94.48** (5.62)	**99.00** (2.62)	**94.25** (8.48)
75+	**92.50** (6.59)	**95.00** (5.62)	**97.25** (4.99)	**83.75** (4.99)	**91.67** (6.83)	**92.25** (8.03)	**97.07** (6.67)	**86.50** (14.34)

[a] Positive: Probe item is a member of the target array
[b] Facilitation: Probe item is a member of the target array and the previous array
[c] Negative: Probe item is not a member of the target array
[d] Recent Negative: Probe item is not a member of the target array but was a member of the previous array

APPENDIX

Table 8. Study 2 Response time data from the Unrelated and Categorized Item Recognition test across the five age groups.

	Response Time (msec) Unrelated List **Mean** (SD)				Response Time (msec) Categorized List **Mean** (SD)			
Age	Positive[a]	Facilitation[b]	Negative[c]	Recent Negative[d]	Positive	Facilitation	Negative	Recent Negative
18-29	**675.21** (101.27)	**678.51** (130.47)	**673.07** (108.42)	**763.87** (138.97)	**711.52** (135.25)	**675.32** (132.5)	**672.36** (142.03)	**782.25** (160.92)
30-44	**791.98** (172.09)	**758.72** (161.08)	**737.12** (150.57)	**896.27** (218.21)	**799.03** (108.67)	**763.05** (139.9)	**738.58** (184.27)	**868.15** (280.38)
45-59	**748.52** (169.03)	**727.79** (156.97)	**728.59** (149.55)	**930.44** (288.58)	**748.73** (162.75)	**754.64** (190.65)	**752.08** (161.37)	**893.62** (257.32)
60-74	**886.40** (153.07)	**863.98** (127.07)	**843.84** (128.25)	**1037.44** (167.2)	**936.78** (196.84)	**869.33** (168.9)	**867.66** (173.7)	**967.72** (174.93)
75+	**911.34** (185.47)	**882.53** (176.89)	**931.90** (203.53)	**1118.53** (310.21)	**962.76** (214.82)	**942.46** (176.96)	**961.08** (220.95)	**1160.50** (287.81)

[a] Positive: Probe item is a member of the target array
[b] Facilitation: Probe item is a member of the target array and the previous array
[c] Negative: Probe item is not a member of the target array
[d] Recent Negative: Probe item is not a member of the target array but was a member of the previous array

APPENDIX

Table 9. Raw scores from the Perceptual Speed Measures for the different age groups in Study 2.

Age Group	Letter Comparison Mean (S.D.)	Pattern Comparison Mean (S.D.)
18-29	**10.53** (2.76)	**19.03** (3.00)
30-44	**9.00** (2.61)	**17.08** (3.82)
45-59	**9.38** (2.30)	**15.90** (2.41)
60-74	**6.48** (2.00)	**13.03** (2.81)
75+	**6.50** (1.56)	**11.20** (1.83)

APPENDIX

Table 10. Results from the hierarchical regression analyses for the recent negative condition in Study 2.

	Accuracy Data		Response Time Data	
Controlled Variable	R^2	Increase in R^2	R^2	Increase in R^2
Age	0.13*		0.05*	
Speed Composite	0.19*		0.09*	
Age	0.20*	0.01	0.09*	0.00

$p < .05$

APPENDIX

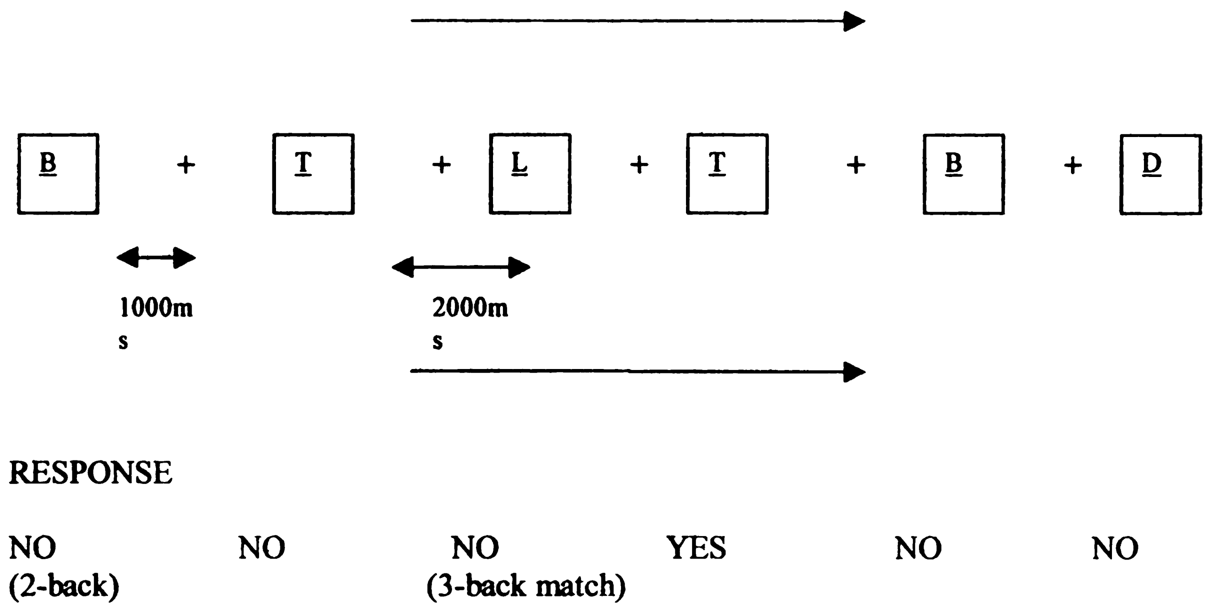

Figure 1. Figural Description of the N-back task.

APPENDIX

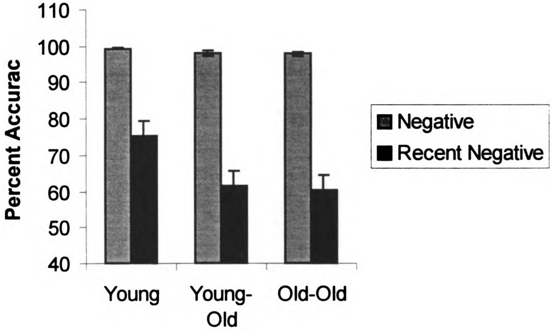

Figure 2. A Comparison of Accuracy Data in the Negative and Recent Negative conditions for the 2-back task.

APPENDIX

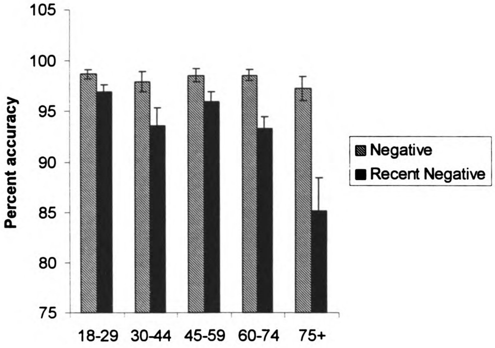

Figure 3. Study 2 Comparison of Recent Negative and Negative Accuracy data for the Item Recognition task across the five age groups.

APPENDIX

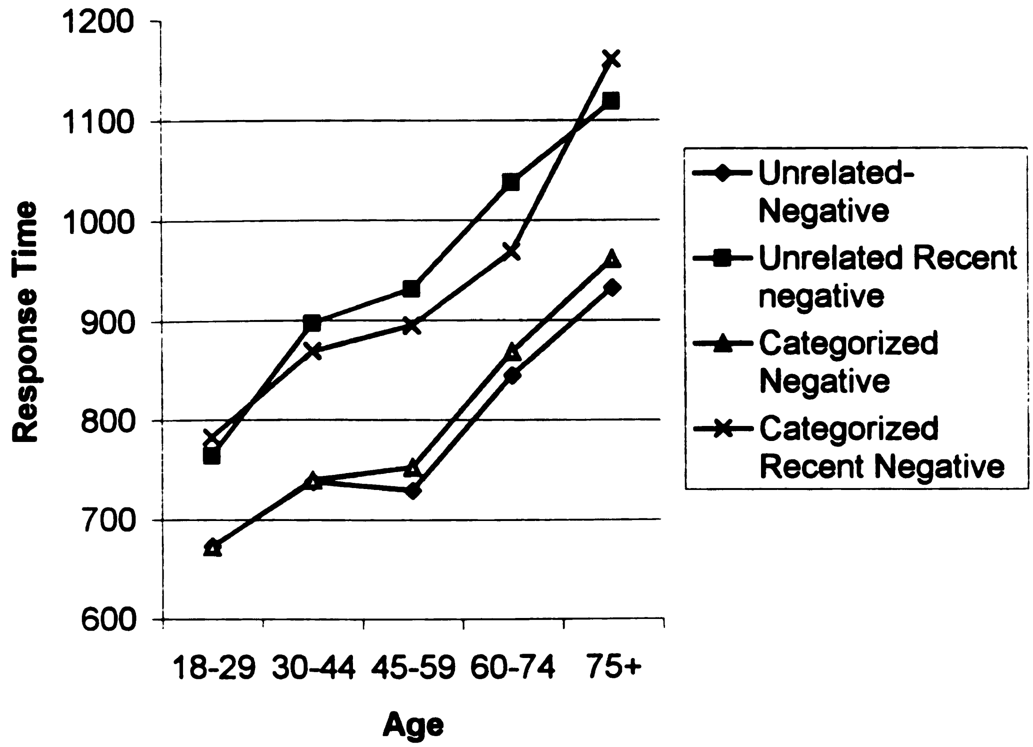

Figure 4. Response time for the Negative and Recent Negative Conditions for the Categorized and Unrelated Lists.

APPENDIX

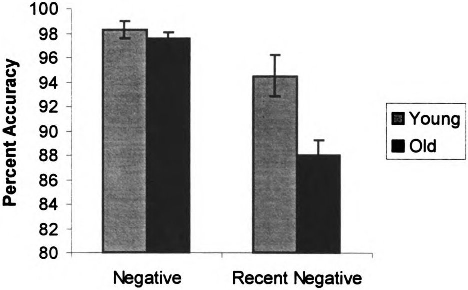

Figure 5. Item Recognition Accuracy Performance comparing Young and Old Adults collapsed across studies.

APPENDIX

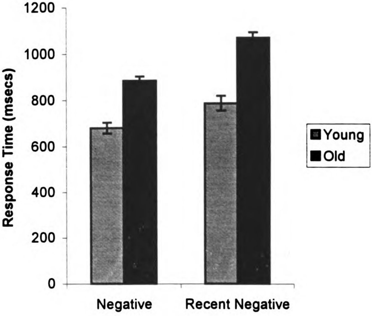

Figure 6. Item Recognition Response Time data comparing Young and Old adults collapsed across studies.

REFERENCES

REFERENCES

Anders, T. R. & Fozard, J. L. (1973). Effects of age upon retrieval from primary and secondary memory. Developmental Psychology, 9, 411-415.

Anders, T. R., Fozard, J. L, & Lillyquist, T. D. (1972). Effects of age upon retrieval from short-term memory. Developmental Psychology, 6, 214-217.

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 Experimental Neuropsychology, 13, 909-922.

Arbuckle, T. Y. & Gold, D. P. (1993). Aging, inhibition, and verbosity. Journal of Gerontology: Psychological Sciences, 48, P225-P232.

Awh, E., Jonides, J., Smith, E. E., Schumacher, E. H., Koeppe, R. A., & Katz, S. (1996). Dissociation of storage and rehearsal in verbal working memory: Evidence from PET. Psychological Science, 7, 25-31.

Baddeley, A. D. (1992). Working Memory. Science, 225, 556-559.

Baddeley, A. D. & Hitch, G. J. (1994). Developments in the concept of working memory. Neuropsychology, 8, 485-493.

Battig, W. F. & Montague, W. E. (1969). Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. Journal of Experimental Psychology, 80, 1-46.

Beck, A. T. (1978). Beck Depression Inventory. San Antonio, TX: Psychological Corporation.

Berman, K., F., Ostrem, J. L., Randolph, C., & Gold, J. (1995). Physiological activation of a cortical network during performance of the Wisconsin Card Sorting Test: A positron emission tomography study. Neuropsychologia, 33, 1027-1046.

Bjork, R. A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. In H.L. Roediger and F.I.M. Craik (Eds.) Varieties of Memory and Consciousness. Essays in Honour of Endel Tulving. New Jersey: Lawrence Erlbaum Associates.

Bjork, E. L. & Bjork, R. A (1996). Continuing influences of to-be-forgotten information. Consciousness and Cognition, 5, 176-196.

Braver. T. S., Cohen, J. D., Nystrom, L. E., Jonides, J., Smith, E. E., & Noll, D. C. (1997). A parametric study of prefrontal cortex involvement in human working memory. Neuroimage, 5, 49-62.

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

Butler, K. M., Zacks, R.T., & Henderson, J. M. (1999). Suppression of reflexive saccades in younger and older adults: Age comparison on an antisaccade task. Memory and Cognition, 27, 584-591.

Carlson, M.C., Hasher, L., Connelly, & Zacks, R. T. (1995). Aging, distraction, and the benefits of predictable location. Psychology and Aging, 10, 427-436.

Chao, L. L. & Knight, R. T. (1997). Prefrontal deficits in attention and inhibitory control with aging. Cerebral Cortex, 7, 63-69.

Christensen, H., MacKinnon, A., Jorm, A.F., & Henderson, A.S. (1994). Age differences and interindividual variation in cognition in community dwelling elderly. Psychology and Aging, 9, 381-390.

Coffey, C. E. (2000). Anatomic imaging of the aging human brain. In C. E. Coffey & J. L. Cummings (Eds.) Textbook of Geriatric Neuropsychiatry. Washington: American Psychiatric Press, Inc.

Cohen, J. D., Perlstein, W. M., Braver, T. S., Nystrom, L. E., Noll, D. C., Jonides, J., & Smith, E. E. (1997). Temporal dynamics of brain activation during a working memory task. Nature, 386, 604-608.

Connelly, S. L., & Hasher, L. (1993). Aging and inhibition of spatial location. Journal of Experimental Psychology: Human Perception and Performance, 19, 1238-1250.

Connelly, S. L., Hasher, L. & Zacks, R. T. (1991). Age and reading: The impact of distraction. Psychology and Aging, 6, 533-541.

Craik, F. I. M. & Anderson, N. D. (1999). Applying cognitive research to problems of aging. In D. Gopher & A. Koriat (Eds.) Attention and Performance XVII.

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. New York: Plenum Press.

Cronin-Golomb, A. (1990). Abstract thought in aging and age-related neurological disease. In F. Boller and J. Grafman (Eds.) Handbook of Neuropsychology, Vol 4. Elsevier Science Publishers.

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.

Dobbs, A. R. & Rule, B. G. (1989). Adult age differences in working memory. Psychology and Aging, 4, 500-503.

Erikson, C. W., Hamlin, R. M., & Daye, C. (1973). Aging adults and rate of memory scan. Bulletin of the Psychonomic Society, 1, 259-260.

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.

Fuster, J. M. (1997). The Prefrontal Cortex. Anatomy, Physiology, and Neuropsychology of the Frontal Lobe. Third Edition. New York: Lippincott-Raven.

Geiselman, R.E. & Bagheri, B. (1985). Repetition effects in directed forgetting: Evidence for retrieval inhibition. Memory and Cognition, 13, 57-62.

Gerard, L., Zacks, R. T., Hasher, L. & Radvansky, G. A. (1991). Age deficits in retrieval: The fan effect. Journal of Gerontology: Psychological Sciences, 46, P131-136.

Gevins, A. & Cutillo, B. (1993). Spatiotemporal dynamics of component processes in human working memory. Electroencephalography and clinical Neurophysiology, 87, 128-143.

Gold, T. Y., & Arbuckle, D. P. (1995). A longitudinal study of off-target verbosity. Journal of Gerontology: Psychological Sciences, 50B, P307-315.

Gur, R. C., Gur, R. E., Obrist, W. D., Skolnick, B. E., & Reivitch, M. (1987). Age and regional cerebral blood flow at rest and during cognitive activity. Archives of General Psychiatry, 44, 617-621.

Hamm, V. P. & Hasher, L. (1992). Age and the availability of inferences. Psychology and Aging, 6, 587-594.

Hartman, M., & Hasher, L. (1991). Aging and suppression: Memory for previously relevant information. Psychology and Aging, 6, 587-594.

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. Journal of Experimental Psychology: Learning, Memory and Cognition, 17, 163-169.

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

Hasher, L. Zacks, R. T. & May, C. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.) Attention and Performance, XVII, Cognitive Regulation of Performance: Interaction of Theory and Application. Cambridge, MA: MIT Press.

Haug, H. & Eggers, R. (1991). Morphometry of the human cortex cerebri and corpus striatum during aging. Neurobiology of Aging, 12, 336-338.

Heaton, R. K., Chelune, G. J., Talley, J. L., Kay, G. G. & Curtiss, G. (1993). Wisconsin Card Sorting Test Manual: Revised and Expanded. Odessa: Psychological Assessment Resources, Inc.

Hertzog, C. (1996). Research design in studies of aging and cognition. In J. E. Birren and K. Warner Schaie (Eds.) Handbook of the Psychology of Aging. San Diego: Academic Press.

Jonides, J., Marshuetz, C., Smith, E. E., Reuter-Lorenz, P.A., Koeppe, R. A., & Hartley, A. (2000). Age differences in behavior and PET activation reveal differences in interference resolution in verbal working memory. Journal of Cognitive Neuroscience, 12, 188-196.

Jonides, J., Smith, E. E., Marshuetz, C., Koeppe, R. A., & Reuter-Lorenz, P. A. (1998). Inhibition in verbal working memory revealed by brain activation. Proceedings of the National Academy of Science, 95, 8410-8413.

Just, M. A. & Carpenter, P. A. (1992). A capacity view of comprehension: Individual differences in working memory. Psychological Review, 99, 122-149.

Kausler, D.H., Salthouse, T.A. & Saults, J. S. (1988). Temporal memory over the adult lifespan. American Journal of Psychology, 101, 207-215.

Keys, B. A., & Whiter, D., A. (2000). Exploring the relationship between age, executive abilities, and psychomotor speed. Journal of the International Neuropsychological Society, 6, 76-82.

Koriat, A., Ben-Zur, H., & Sheffer, D. (1988). Telling the same story twice: Output monitoring and age. Journal of Memory and Language, 27, 23-39.

Kuchera, H. & Francis, W. (1967). Computational analysis of present-day American English. Providence, RI: Brown University Press.

Kramer, A. F., Humphrey, D. G., Larish, J. F., Logan, G., D., & Strayer, D. L. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. Psychology and Aging, 9, 491-512.

Langley, L.K., Overmier, B., Knopman, D.S., & Prod'Homme, M.M. (1998). Inhibition and habituation: Preserved mechanisms of attentional selection in aging and Alzheimer's disease. Neuropsychology, 12, 353-366.

Larrabee, G. J., Trahan, D. E., Curtiss, G., & Levin, H. S. (1988). Normative data for the verbal selective reminding test. Neuropsychology, 2, 173-182.

Lezak M. D. (1995). Neuropsychological Assessment. Third Edition. New York: Oxford University Press.

Li, K. Z., H., & Bosman, E. A. (1996). Age differences in Stroop-like interference as a function of semantic relatedness. Aging, Neuropsychology, and Cognition, 3, 272-284.

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

Lustig, C., Tonev, S. T., & Hasher, L. (2000). Visual distraction and processing speed I. Presented at the Cognitive Aging Conference, Atlanta, Georgia.

May, C. P., Hasher, L. & Kane, M., (1999). The role of interference in memory span. Memory and Cognition, 27, 759-767.

May, C. P., Kane, M., & Hasher, L. (1995). Determinants of negative priming. Psychological Bulletin, 118, 35-54.

Milner, B. (1964). Some effects of frontal lobectomy in man. The frontal granular cortex and behavior. New York: McGraw-Hill.

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

Neumann, E. & DeSchepper, B. G. (1992). An inhibition-based fan effect: evidence for an active suppression mechanism in selective attention. Canadian Journal of Psychology, 46, 1-40.

Osterweil, D., Mulford, P., Syndulko, K., and Martin, M. (1994). Cognitive function in old and very old residents of a residential facility: Relationship to age, education and dementia. Journal of the American Geriatrics Society, 42, 766-773.

Pietrini, P. & Rapoport, S. I. (2000). Cerebral blood flow and glucose metabolism in healthy human aging. In C. E. Coffey & J. L. Cummings (Eds.) Textbook of Geriatric Neuropsychiatry. Washington: American Psychiatric Press, Inc.

Persad, C. C., Abeles, N., Zacks, R. T., & Denburg, N. (in press). Inhibitory changes after age 60 and their relationship to measures of attention and memory. Journal of Gerontology: Psychological Sciences.

Salthouse, T. A. (1991). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. Psychological Science, 2, 179-183.

Salthouse, T. A. (1993). Speed mediation of adult age differences in cognition. Developmental Review, 14, 413-437.

Salthouse, T. A. (1994). The aging of working memory. Neuropsychology, 8, 535-543.

Salthouse, T. A. (1994). Aging associations: Influence of speed on adult age differences in associative learning. Journal of Experimental Psychology: Learning, Memory, and Cognition, 20, 1486-1503.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. Psychological Review, 103, 403-428.

Salthouse, T. A. & Coon, V. E. (1993). Influence of task-specific processing speed on age differences in memory. Journal of Gerontology: Psychological Sciences, 48, P245-P255.

Salthouse, T. A. & Coon, V. E. (1994). Interpretation of differential deficits: The case of aging and mental arithmetic. Journal of Experimental Psychology: Learning, Memory and Cognition, 20, 1172-1182.

Salthouse, T. A. & Meinz, E.J. (1995). Aging, inhibition, working memory, and speed. Journal of Gerontology: Psychological Sciences, 50B, P297-P306.

Schooler, C., Neumman, E., Caplan, L.J. & Roberts, B. R. (1997). Continued inhibitory capacity throughout adulthood: Conceptual negative priming in younger and older adults. Psychology and Aging, 12, 667-674.

Schumacher, E. H., Lauber, E., Awh, E., Jonides, J., Smith, E. E., & Koeppe, R. A. (1996). PET evidence for an amodal verbal working memory system. Neuroimage, 3, 79-88.

See, S. T. K. & Ryan, E. B. (1995). Cognitive mediation of adult age differences in language performance. Psychology and Aging, 10, 458-468.

Shipley, W. C. (1946). Institute of Living Scale. Los Angeles: Western Psychological Services.

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

Smith, E. E. & Jonides, J. (1997). Working Memory: A view from neuroimaging. Cognitive Psychology, 33, 5-42.

Smith, E. E., Jonides, J. & Koeppe, R. A. (1996). Dissociating verbal and spatial working memory using PET. Cerebral Cortex, 6, 11-20.

Speiler, D. H., Balota, D. A., & Faust, M., E. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. Journal of Experimental Psychology: Human Perception and Performance, 22, 461-479.

Sternberg, S. (1966). High speed scanning in human memory. Science, 153, 652-654.

Stuss, D. T. & Benson, D. F. (1984). Neuropsychological studies of the frontal lobes. Psychological Bulletin, 95, 3-28.

Sullivan, M. P. & Faust, M. E. (1993). Evidence for identity inhibition during selective attention in old adults. Psychology and Aging, 8, 589-598.

Tipper, S.P. (1985). The negative priming effect: Inhibitory priming by ignored objects. Quarterly Journal of Experimental Psychology, 37A, 571-590.

Tipper, S. P., Weaver, B., & Houghton, G. (1994). Behavioural goals determine inhibitory mechanisms of selective attention. The Quarterly Journal of Experimental Psychology, 47A, 809-840.

Tonev, S. T., Lustig, C., & Hasher, L. (2000). Visual distraction and processing speed II. Presented at the Cognitive Aging Conference, Atlanta, Georgia.

Verhaegen, P. & Salthouse, T. A. (1997). Meta-analyses of age-cognition relations in adulthood: Estimates of linear and nonlinear age effects and structural models. Psychological Bulletin, 122, 231-249.

Veroff, A. E. (1980). The neuropsychology of aging. Psychological Research, 41, 259-268.

West, R., & Baylis, G. C. (1998). Effects of increased response dominance and contextual disintegration on the Stroop interference effects in older adults. Psychology and Aging, 13, 206-217.

Wickens, D.D. (1972). Characteristics of word encoding. In A.W. Melton & E. Martin (Eds.) Coding Processes in human memory. Washington, DC : Winston.

Wixted, J. T. & Rohrer, D. (1993). Proactive interference and the dynamics of free recall. Journal of Experimental Psychology: Learning, Memory and Cognition, 19, 1024-1039.

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. San Diego: Academic Press.

Zacks, R. T, Radvansky, G., & Hasher, L. (1996). Studies of directed forgetting in older adults. Journal of Experimental Psychology: Learning, Memory and Cognition, 22, 143-156.