ADULT DEVELOPMENT AND NEUROPSYCHOLOGICAL CHARACTERISTICS OF TEMPORAL ORDER AND ITEM MEMORY

by

Barbara Curchack Routhieaux

A Dissertation Submitted to the Faculty of the

DEPARTMENT OF PSYCHOLOGY

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 9 7

UMI Number: 9720711

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

THE UNIVERSITY OF ARIZONA ®
GRADUATE COLLEGE

As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Barbara Curchack Routhieaux

entitled Adult Developmental and Neuropsychological Characteristics of Temporal Order and Item Memory

and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy

Elizabeth L. Glisky — 12/18/96
Elizabeth L. Glisky — Date

Merrill F. Garrett — 12-18-96
Merrill Garrett — Date

Cyma Van Petten — 12/18/96
Cyma Van Petten — Date

Alfred W. Kaszniak — 12/18/96
Alfred W. Kaszniak — Date

Steven Rapczak — 12/18/96
Steven Rapczak — Date

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

Elizabeth L. Glisky — 12/18/96
Dissertation Director
Elizabeth L. Glisky — Date

STATEMENT BY AUTHOR

This dissertation has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this dissertation are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: [illegible]

ACKNOWLEDGEMENTS

This dissertation could not be completed without the help of a number of people. First, I would like to thank Elizabeth L. Glisky for her critical insights, access to participants, emotional support, and realization that I could finish this program even when I was 99% sure I couldn't. Next, Gina Patriarca, my research assistant, kept this project afloat in Tucson while I was in North Carolina by running subjects for long hours, dealing with computer foul-ups and sending data across the country. Third, Merrill Garrett provided support for this dissertation from the McDonnell-Pew Cognitive Neuroscience Program. Thanks also must be given to my other committee members: Steve Rapczak, for the idea to use faces as stimuli; Cyma Van Petten, for her attention to detail and understanding of neurophysiology; and Alfred W. Kasniak, for helping me generate a "finishable" dissertation topic.

Finally, I would like to thank my husband, Rob, for his constant yet loving pressure to continue on, for babysitting our newborn during his fussiest times so that I could write, and for being a great example of how to be a successful, organized, academic.

TABLE OF CONTENTS

TABLE OF CONTENTS - *continued*

LIST OF TABLES

ABSTRACT

Research with neurologically impaired patients suggests that temporal order memory (TOM) and item memory (IM) are associated with the frontal lobes and medial-temporal lobes, respectively. Issues concerning the aging of TOM and IM still remain. First, the frontal lobes may show greater age-related decline than posterior portions of the brain and/or the right hemisphere may show greater decline than the left. Second, TOM and IM may or may not be independent, because findings of double dissociations have not been replicated. Third, the relationship between TOM for items in primary vs. secondary memory is unknown. Finally, the mechanisms controlling TOM are poorly understood, partly because many TOM tests maximize working memory demands, thus masking the roles of strategy, sequencing and inhibition. Thirty-two college-age and 32 older participants completed four sets of TOM and IM tests, each of which measured left- or right-hemisphere function (words vs. faces) and maximized or minimized working memory demands. Participants also completed neuropsychological tests of frontal-lobe function. Composite measures of frontal-lobe and medial-temporal-lobe status based on the age-independent performance on additional neuropsychological tests were used to categorize participants as above or below the mean. These composites

were used to predict TOM and IM performance, thus measuring their independence. Results showed greater age-related declines in TOM than IM, regardless of whether faces or words were studied, supporting the frontal-lobe hypothesis of aging. The right-hemisphere hypothesis of aging was not supported. IM and TOM were not found to be independent on any of the four sets of tests. However, frontal-lobe status but not medial-temporal-lobe status predicted TOM performance when one or more test item was in primary memory. Frontal-lobe status did not predict IM performance, regardless of whether items were in primary or secondary memory, suggesting that the frontal-lobes may be specifically involved in TOM when information must be held in mind. Correlations between TOM and neuropsychological tests yielded limited support for the theory that cognitive sequencing is involved in TOM.

CHAPTER 1 - INTRODUCTION

The prefrontal cortex of the human brain is currently a topic of extensive research, so much so that special issues of journals, edited books, as well as entire conferences are being devoted specifically to this topic (Duffy & Campbell, 1994; Fuster, 1995; Grafman, Holyoak, & Boller, 1995; Levin, Eisenberg & Benton, 1991; Passingham, 1993). The prefrontal cortices have traditionally been theorized to mediate such constructs as personality and complex reasoning. Now researchers are beginning to implicate the prefrontal cortex in memory (Bondi, Kaszniak, Bayles, & Vance, 1993; Glisky, 1995; Horel, 1994; Moscovitch & Winocur, 1995; Petrides, 1995; Schacter, 1987; Shimamura, 1995; Shimamura, Janowsky & Squire, 1991; Stuss, 1991). This emphasis on prefrontal cortical function is quite different than traditional memory research, which has emphasized the roles of the medial temporal lobes. Studies of patients with brain damage suggest that the medial temporal lobes are involved in forming new memories for facts and events, memories that can be declared (e.g. Squire, 1994; Moscovitch, 1994). These memories can be referred to as item memories. In contrast, studies of patients with damage to the frontal lobes suggest that the prefrontal cortex may mediate other aspects of memory, including active encoding and retrieval strategies (Petrides, 1995; Tulving et al., 1994) memory for contextual information (e. g. Janowski, Shimamura, & Squire, 1989), and frequency estimation (e.g. Smith & Milner, 1988).

Another aspect of memory thought to be mediated by the frontal lobes is temporal order memory (TOM): the ability to remember which of two previous events occurred more recently. TOM is presumed to be necessary in order to remember when an event occurred, such as whether medication was taken before or after lunch (e.g. Kausler, Lichty and Davis, 1985). In addition, TOM may be required in order to generate plans that require monitoring behavior over time, such as stopping at several destinations during a day's outing (e.g. Fuster, 1985). TOM deficits are observed in several patient populations that involve frontal lobe damage, including those with Parkinson's disease (e.g. Cooper, Sagar & Sullivan, 1993), multiple sclerosis (Beatty & Monson, 1991), Korsakoff's syndrome (e.g. Hunkin & Parkin, 1993) and surgical ablations of the frontal lobes for tumor or epilepsy (e.g. McAndrews & Milner, 1991; Milner, Corsi, & Leonard, 1991). The actual prefrontal structures that are required for TOM, however, are still uncertain, as researchers debate the relative necessity of the dorsolateral, ventromedial and orbitofrontal areas on TOM tasks (Goldman-Rakic, 1995; Fuster, 1995; Petrides, 1995). In addition, many theories have been proposed to explain TOM impairment (Kesner, 1993; McAndrews & Milner, 1991;

Moscovitch & Winocur, 1995; Petrides, 1995; Sullivan & Sagar, 1989; Shallice & Burgess, 1991; Shimamura, 1995).

Like patients with brain damage, many older individuals report difficulty remembering the relative order of events. These anecdotal statements have been verified in the laboratory. In general, young adults display better TOM than older adults (Kausler et al., 1985; McCormack, 1982, 1984; Naveh-Benjamin, 1990; Spencer & Raz, 1994). However, TOM research with older participants is only now beginning, and there is still debate as to the nature of the changes in TOM associated with aging.

The purpose of this dissertation is to address four separate but related issues important to understanding the nature of TOM. First, it addresses the nature of age-related changes in TOM in relationship to other forms of memory, specifically item memory (IM). Second, it addresses the roles of the prefrontal and medial temporal cortices in TOM and IM, and provides some clues as to which areas of the prefrontal cortex are involved. Third, it addresses the issue of whether TOM is lateralized, with the left hemisphere supporting temporal processing of verbal information, and the right hemisphere supporting temporal processing of information that is difficult to verbally encode. Finally, it addresses the extent to which TOM depends on good primary memory function and considers in particular those theories that suggest that TOM decline is a result of working memory impairment.

In order to address these separate but related issues, several areas of research will be critically reviewed and research questions arising from each review will be summarized. First, neuropsychological theories of adult development and age-related changes in TOM will be reviewed. Next, the current understanding of the neural substrates involved in TOM and IM will be reviewed and evidence concerning the laterality of TOM in patients with unilateral brain lesions will be presented. Third, the ways in which neuropsychologists assess the frontal lobes will be reviewed, followed by a discussion of the neuropsychological mechanisms that may underlie TOM performance. Finally, the possibility that commonly used methodologies to test TOM rely heavily on primary memory or working memory will be considered, followed by the presentation of a methodology that assesses TOM independent of primary memory function.

Cognitive Neuropsychological Theories of Aging

Researchers studying the effects of aging on the brain have proposed two contrasting theories. One postulates that anterior brain areas deteriorate at a faster rate than posterior brain areas. Kuhl and colleagues' (Kuhl, Metter, Riege, & Phelps, 1982; Kuhl, Metter, Riege & Hawkins, 1984) research with Positron Emission Tomography (PET) suggested a mild decrease in metabolic rates in the frontal region of old compared with young individuals. On an anatomic level, Haug et al. (1983) found little neuronal degeneration in striate and parietal cortex associated with age, but estimated between a 15% and 20% loss of neuronal cells of prefrontal cortex between young adulthood and old age. Using Magnetic Resonance Imaging (MRI), Coffey et al. (1992) reported a 0.55% decrease in volume in the frontal lobes per year compared with a 0.28% yearly decrease in temporal lobes, and 0.30% yearly decrease in amygdala and hippocampal formations. In addition to anatomical and physiological research, psychometric (functional) approaches have also suggested that people perform poorly on tests of frontal lobe function as they age (e.g. Hart, 1988; for review, see LaRue, 1992).

Another theory of neuropathological changes associated with aging has postulated that the right hemisphere deteriorates at a faster rate than the left hemisphere (Klisz, 1978; Schaie & Schaie, 1977). Schaie & Schaie (1977) and Klisz (1978) generated this "right hemisphere" theory because older people's performance on the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1958) and Halstead-Reitan Neuropsychological Battery (Reitan & Davison, 1974) showed greater decline on "right hemisphere tasks" than "left hemisphere tasks." In addition, on more selective measures, older participants generally performed worse on visuoconstructive tasks such as cube drawing and perception (Plude, Milberg, and Cerella, 1986) than on verbal tasks. They also tended to perform more poorly on "nonverbal" intelligence tasks such as the Raven's Progressive Matrices (Raven, 1960; Wilson et al., 1975) than verbal ones. Compared to their performance 21 years ago, participants in their sixties performed more poorly on the Space subtest of the SRA Primary Mental Abilities Test (Thurstone & Thurstone, 1949) than both the SRA Verbal Meaning subtest and estimates of the general intelligence factor "g". (Hertzog & Schaie, 1988). Van Gorp, Satz, & Matrushina (1990) found that between the ages of 58 and 85, participants showed a substantially greater decline on the Visual Reproduction subtest (57%) than the Logical Memory subtest (19%) of the Wechsler Memory Scale, consistent with greater right hemisphere decline.

Some evidence, however, has countered the right hemisphere hypothesis of aging. For instance, older participants may have performed particularly poorly on the Visual Reproduction subtest because the test relies on planning and organization to a greater extent than does Logical Memory. Also, results of age-related changes on memory tasks that rely more exclusively on a single hemisphere have recently suggested that age affects verbal memory more than nonverbal memory (Janowski, Carper, & Kaye, 1996). Further, neuroanatomical and neurophysiological evidence has not indicated that the right hemisphere declines faster than the left hemisphere. Because of this contradictory evidence, the right hemisphere hypothesis remains a topic of discussion (Libon et al., 1994).

These alternative theories of neuropsychological function make different predictions. Proponents of the theory of preferential frontal lobe decline predict that as people age, they should perform more poorly on tasks of frontal function than on tasks that tap posterior functions, regardless of which hemisphere mediates the tasks. Thus, the frontal lobe hypothesis predicts greater decline in TOM than IM for both verbal and nonverbal materials. Proponents of the right hemisphere hypothesis predict that older participants' performance should be worse on tasks which utilize the right hemisphere, regardless of the cortical/subcortical areas that are involved. The right hemisphere hypothesis thus predicts greater declines in nonverbal than verbal cognitive tasks with no difference in TOM and IM overall. Presumably, if both hypotheses are correct, interactions between the type of memory and type of materials used are also possible.

Age-related Changes in Temporal Order Memory

In the 1980s, TOM was studied in older adults, primarily in response to a debate in cognitive psychology concerning whether TOM constituted an automatic process or an effortful one (Hasher & Zacks, 1979). According to Hasher and Zacks (1979), if TOM was automatic, it should be developmentally invariant, insensitive to encoding manipulations or intentionality at encoding, and should show few individual differences across participants. Consistent with this hypothesis, Perlmutter, Metzger, Nezworski, and Miller (1981) found no age-related decline in TOM when comparing young (mean age = 20) students and old (mean age = 64) alumni of the University of Minnesota. In this study, Perlmutter et al. (1981) used what is perhaps the most frequently utilized method of measuring temporal order memory, the continuous temporal ordering task (CTO; also called recency discrimination). In this task, items are presented one at a time, and participants are told to try to remember the order in which they were presented. Interspersed among study items are test pairs consisting of two items that were seen earlier in the list. Participants must decide which item they saw more recently. Perlmutter et al.'s (1981) failure to find age effects supported the notion that TOM is an automatic process. McCormack (1981), using a task in which participants studied a list of 50 items and then reported the tenth of the list from which each item was presented, initially found age-related decline in TOM. He reported, however, that older adults were biased in their response style -- they tended to assign fewer words to the beginning and ending tenths of the list than young participants. When participants were forced to put only five items into any one category, no age effect was observed for TOM.

Later studies, however, found evidence that conflicted with Hasher and Zacks' (1979) hypothesis of developmental stability in TOM. McCormack (1982) could not replicate his earlier finding with a recency discrimination task, but instead found that older females (mean age = 68.3) performed more poorly than young females (mean age = 21.2). McCormack (1984) then replicated the age-related changes in TOM on a list discrimination task. On this task, participants listened to two lists and then were asked which words came from the first list and which came from the second. Similar findings were obtained by Kausler et al. (1985). Their young adults (mean age = 20.7) and older adults (mean age = 71.2) performed 4 blocks of 4 distinctly different cognitive tests for 90 s each. Some participants were told to remember the temporal order of the tests, some were told that their memory would be assessed for the tests they received, and some were unaware that any memory testing would follow. Results supported the notion that TOM declines with age. Spencer and Raz (1994) found a similar decline in memory for order of cognitive activities performed over a three week period. Kausler, Salthouse, and Saults (1988) also observed age-related decline on a test in which participants studied a list of 16 items with intention to remember their temporal order. They were then asked to order the items, which were presented randomly at test. Participants were also given a paired-associate learning test, on which age-related decline was also found. Naveh-Benjamin (1990) replicated Kausler et al.'s (1988) results, with a 20 item list, finding a greater age-related decline on a TOM test than on an IM test for the same items. They did not report, however, the actual performance of these participants on the IM test.

Several conclusions can be reached from the above results. It is now generally accepted that TOM for verbal information decreases as adults grow older. This age-related decline is observable with a variety of methodologies, including recency discrimination, memory for order of activities, list discrimination, and serial ordering.

Several questions still remain concerning the nature of TOM in older adults. First, from the research presented above, it is unclear whether or not TOM requires the same cognitive mechanisms as those used for IM, which also declines as participants age (for reviews, see Schacter, Kaszniak, & Kihlstrom, 1991; Shimamura, 1990). IM and TOM were tested together in only two of the above studies. Kausler et al. (1985) found that memory for performed behaviors increased when participants were told to try to remember them rather than receiving no instructions that a memory test would follow. In these same participants, memory for temporal order of the behaviors was unaffected by intentionality. That is, memory for order did not improve when participants knew that a TOM test would be given. However, they found that the performance on a paired-associate memory task was strongly correlated with serial ordering performance. From this research, it remains unclear whether the IM and TOM decline at the same or differential rates, and whether they depend on the same or different mechanisms. In contrast to the research using words, TOM for information that is difficult to verbally encode has yet to be tested in older adults. Given the possible difference between right and left hemisphere functioning in aging, it may be important to test TOM with materials that may place differential demands on the two hemispheres.

Localization of the Brain Systems Controlling Temporal Order and Item Memory

Many researchers who study TOM assume that it depends on a different brain system than IM. Support for this view would be strengthened if researchers found a double dissociation between the two kinds of memory tests. For a double dissociation to occur, an individual with one type of brain injury performs poorly on one but not another task. An individual with another type of brain injury shows the opposite pattern of performance. Neuropsychologists have attempted to find double dissociations between TOM and IM in patients with frontal vs. medial temporal lobe lesions. The evidence for the independence of TOM and IM, however, is equivocal.

One paradigm that has been created to test the independence of TOM and IM involves a modification of the continuous temporal order task, described above. Participants view a large number of items and are asked to remember them as well as the order in which they are presented. Then, interspersed between the items are test trials in which TOM or IM is assessed. As described above, TOM is assessed by showing participants two items that they have previously seen and asking which came first. IM is assessed by showing participants one item they viewed along with a novel item and asking which they studied. Stimuli are usually tested at predetermined intervals from initial study so that retention interval is varied (i.e. items that occurred 3 stimuli ago, 6 stimuli ago, 10 stimuli ago, etc.). Thus, in the same continuous memory paradigm, both IM and TOM are tested at various retention intervals. In addition, the number of intervening items, or lag, between two TOM test items may also be varied and measured.

When performance for retention interval and lag are reported, individuals with no history of brain injury show a consistent pattern of performance. Generally, for IM, as the retention interval increases, performance decreases. Thus, IM is most accurate for items presented with fewer intervening items between study and test. It is least accurate when a large number of items intervene between study and test. For example, Sullivan and Sagar (1989) found that on a verbal continuous IM test, normal older individuals' performance was 100% when no items intervened between study and test, was 80% when 10-25 items intervened, and was 69% when 50-150 items intervened. On a nonverbal analogue, older individual's performance also declined as a function of retention interval, but the level of decline was much flatter than the verbal task. Decreased IM as a function of increased retention interval has been replicated in a number of studies in both older (Cooper et al., 1993) and middle aged (Beatty & Monson, 1991) adults.

For continuous TOM tasks, both retention interval and lag are of interest. Retention interval has the same effect on TOM as IM. That is, as the interval between the most recent study item and its test increases, TOM decreases (Beatty & Monson, 1991; Cooper et al., 1993; Milner et al., 1991; Perlmutter et al., 1981; Sagar & Sullivan, 1989). Effects of lag are not as consistent as retention interval. Most researchers do not consistently use the same lags for each retention interval. Rather, they pick certain retention intervals and then test all possible pairings of the intervals. Thus, if retention intervals of 1, 3, 6, and 10 are chosen, the test pairs have lags of one (1-3), two (3-6), three (6-10), four (1-6), six (3-10), and eight (1-10). Lag and recency then become confounded and their independent effects can not be assessed. In addition, the longest retention intervals vary widely between experiments, ranging from 10 to 150. Given this variability, it is not surprising that lag effects have been equivocal. Milner et al. (1991) found that as the number of items intervening between studied items increases, the better people are at making temporal order judgements. However, others have found no effect of lag (Cooper et al., 1993; Perlmutter et al., 1981; Sagar, Sullivan, Gabrieli, Corkin, & Growdon, 1988). An interaction between retention interval and lag has been found, in which long lags are associated with better memory at short retention intervals (Perlmutter et al., 1981). However, this interaction is not always observed (Cooper et al., 1993). A theoretical rationale for picking the lags and retention intervals would aid in the understanding of their effects and interactions. Results of studies attempting to dissociate IM and TOM using the continuous memory task are summarized below.

Corsi (presented in Milner, 1971) found that patients with frontal lesions performed poorly on recency discrimination tasks and normally on IM tasks compared to normal controls and patients with temporal lobe lesions. In contrast, he found that patients with temporal lobe lesions performed worse than normal controls and patients with frontal lesions on IM tests, but these patients performed normally on recency judgement tasks. The patients with temporal lobe lesions performed above chance on the IM tests, possibly because memory was measured by two-alternative forced choice method, or possibly because other cognitive functions were involved. Shimamura, Janowski, & Squire (1990), however, were unable to replicate the double dissociation between TOM and IM. Although their patients with frontal lesions were impaired on a serial order memory test for a list of 15 items, but not impaired on an IM test of the same items, individuals with medial temporal lobe lesions were impaired on both TOM and IM tests. Milner et al. (1991) also only partially replicated the double dissociation between TOM and IM on the continuous memory tasks. They tested patients with unilateral lesions affecting either the frontal or temporal lobes with three kinds of materials -- concrete words, representational drawings, and abstract designs. In the word condition, patients with left frontal lesions were impaired on TOM but not IM tests, but patients with left temporal lobe lesions were not impaired on either TOM or IM tests. For representational drawings, only patients with right frontal lobe damage were impaired on the TOM test, but all participants performed at ceiling on the IM test, thereby precluding a double dissociation. However, Milner et al. (1991) obtained a double dissociation with right hemisphere frontal and temporal lobe patients when using the abstract designs. Patients with right frontal lesions were impaired on the TOM task, but not on the IM task, whereas patients with right temporal lobe lesions showed the opposite pattern of performance. Even though the dissociation was reliable, frontal lobe patients' IM performance was more similar to the temporal lobe patients (81% vs. 78%.) than normal controls (92%), indicating that both frontal lobe damage and temporal lobe damage may lead to impaired IM performance. A strong demonstration of the dissociability of these two types of memory has yet to be reported.

Researchers have also questioned whether the left and right frontal lobes are specialized for verbal and nonverbal TOM respectively. Findings from Milner et al.'s (1991) continuous memory tests for verbal and nonverbal information were equivocal. For the abstract paintings, whose processing supposedly taps right hemisphere functioning, patients with right prefrontal cortical damage performed worse on the TOM test than patients with left prefrontal cortical damage. In addition, patients with right temporal lobe lesions performed worse than all other patients on the corresponding IM tasks. For the concrete nouns, however, patients with damage to either frontal lobe were impaired on the TOM test. These findings suggested that right and left prefrontal cortices may have differential roles in processing temporal order, but the nature of these roles and the particular prefrontal cortical areas responsible for TOM were unclear.

Sullivan and Sagar (1989) also reported equivocal findings from a patient with Parkinson's disease. This patient had left unilateral motor signs, implicating right frontal lobe/basal ganglia pathology. On a verbal continuous memory test with TOM and IM components, the patient was unimpaired compared to normal controls. On a nonverbal analogue, which used abstract wallpaper designs as stimuli, the patient was impaired on both the TOM and IM tests. The authors analyzed the data further by categorizing test pairs by retention interval. They found that, for the nonverbal IM test, the patient was impaired only at the shortest interval between study and test. That is, the patient's IM was impaired only for those items that appeared just before they were tested. The patient was also impaired on the nonverbal TOM items compared to verbal TOM items, with performance hovering around chance (57%) at a three-item retention interval. Sullivan and Sagar (1989) interpreted this finding as supporting a specialization of the right frontal lobes and basal ganglia in nonverbal short-term memory. No replication of this finding has been reported. In addition, they did not report a patient with right side motor signs (i.e. greater left hemisphere pathology). Therefore, although suggestive, the laterality of TOM remains in question.

In summary, there is not yet clear evidence that IM and TOM are supported by different brain structures. Although a double dissociation has been found twice, it could not be replicated in other studies. Research concerning the laterality of brain structures mediating TOM suggest that, to the extent that TOM is reliant on short-term memory, the hemispheres may be specialized for different types of information in mind. However, the findings have not been replicated; nor have they been entirely consistent. In addition, the retention intervals and lags in continuous memory paradigm vary greatly across research labs and are usually confounded. Use of a continuous memory paradigm that unconfounds these two variables may help researchers explain their results.

Neuropsychological Assessment of the Prefrontal Cortex

Several tests have been purported to measure the function of the prefrontal cortex, and some tests have been associated with discrete areas of this brain region. Use of these tests in the understanding of the prefrontal cortex are reviewed below.

Perhaps the most utilized neuropsychological test of frontal functioning has been the Wisconsin Card Sorting Test (WCST; Heaton, 1981). On this test, individuals must figure out three principles by which cards may be sorted, and sort the cards correctly based on examiner feedback. The correct principle to sort the cards switches after a certain number of correct card sorts, and the individual must discern this switch and sort by a different principle. Patients with frontal lobe lesions perform more poorly on this test than patients with non-frontal lesions (Robinson, Heaton, Lehman, & Stilson, 1990). Patients with dorsolateral prefrontal cortical lesions seem to be particularly impaired (Milner, 1964). These findings have been questioned, however, because some non-frontal types of brain damage have also been associated with deficits on the WCST (Anderson, Damasio, Jones, & Tranel, 1991). Nevertheless, PET evidence in normal participants has pointed to the dorsolateral prefrontal cortex as involved in performance on the WCST (Berman et al., 1995). In addition, performance on the WCST has been shown to decline with age, consistent with the notion of differential frontal decline in the elderly (e.g. Parkin & Lawrence, 1994).

The Controlled Oral Word Association Test (FAS; Benton & Hamsher, 1976) has also been purported to measure frontal function. On this test, individuals are asked to generate as many words as they can that begin with the letters F, A, and S. For each letter, individuals have 60 seconds to generate responses. Patients with left frontal lobe damage have been observed to be impaired on this task (Benton, 1968; Crowe, 1992; Milner, 1964). In addition, evidence from PET studies of normal participants has also implicated the frontal lobes, specifically the left dorsolateral prefrontal cortex (Frith, Friston, Liddle, & Frackowiak, 1991). FAS performance has also been found to decline with age and has been shown to be unrelated to IM ability (Parkin & Lawrence, 1994). This evidence, although indirect, suggests that age-related FAS decline is related to frontal pathology, given the independence from IM and relative known decline of the frontal cortex with age.

Two cognitive skills that the FAS and WCST share are on-line monitoring and strategy use. Both tasks require that individuals hold in mind prior responses in order to produce acceptable future responses. For instance, on the WCST, examinees must remember how they sorted the cards in the past as well as the feedback they have gotten from the examiner in order to decide how to sort the cards at present. In addition, both tasks require some type of strategic planning. For instance, on the COWA, participants may perform better if they use a phonemic strategy, i.e. generating words that sound the same, like flat, fat, and frat. The exact nature of the strategies involved, however, is as yet unclear.

Researchers have proposed that monitoring of information on line and use of strategy are part of the working memory system (Baddeley, 1986). Baddeley (1994) has defined working memory as "the system for the temporary maintenance and manipulation of information, necessary for the performance of such complex cognitive activities as comprehension, learning, and reasoning, p. 351)". Accordingly, it allows an individual to represent the past temporarily so that it may be reflected upon and further action can be actively chosen. Three components make up the working memory system: the articulatory loop, the visuospatial scratchpad, and the central executive. The first two components are specialized for the maintenance of speech-based and visuospatial information, respectively. The articulatory loop has been associated with left inferior parietal functioning (Warrington & Shallice, 1969). The visuospatial scratchpad has been associated with right parietal, bilateral temporo-occipital regions and right temporal and right inferior frontal areas (Farah, Hammond, Levine, & Calvanio, 1988). The functioning of the central executive has been based on Shallice & Burgess' (1991) Supervisory Attentional System. According to this theory, the central executive is responsible for processing when novel or non-routine strategies are needed for accurate performance. The central executive must inhibit routine strategies when inappropriate and select and implement novel ones. Patients with frontal lobe damage have appeared to show central executive deficits on a wide variety of tasks, and there has been considerable variability, depending on the task chosen. Consequently, Baddeley (1994) has proposed that the central executive may actually be a constellation of systems rather than a single controlling one.

Given this description of working memory, any task that requires both the maintenance and manipulation of verbal or nonverbal information can be considered a working memory task. Both the WCST and FAS are working memory tasks due to their dependence on "on-line" monitoring and choice of strategy for adequate performance. Three other neuropsychological tasks also fit the working memory description. First, the WAIS-R Digit Span-Backwards subtest has a working memory component. On this task, individuals listen to a series of number strings and must say them back to the examiner in reversed order. This task requires maintenance of the numbers on line as well as the manipulation of them to put them in reverse order. Second, the WAIS-R Arithmetic Subtest is a working memory test, because it requires individuals to do mental math problems. These problems require the maintenance of the parts of the problems in mind while mental operations are performed on them. In addition, individuals must choose the appropriate mathematical operation to complete each task. Finally, the WMS-R Mental Control subtest can be said to be a working memory task. On this task, individuals, must say the alphabet as quickly as they can, count backwards from 20, and complete a serial addition task on which participants add threes serially, starting with one (1, 4, 7, . . .). Most of the variability on this task comes from the serial addition portion, which requires maintaining a number in mind, applying an addition rule to it, and then updating to a new solution number.

Other tasks have been implicated as frontal lobe tasks but not specifically as working memory tasks. Two such tests, the WAIS-R Picture Arrangement test (Wechsler, 1981) and WAIS-RNI Sentence Arrangement Test (Kaplan, Fein, Morris, & Delis, 1991), have strong strategic components but do not require maintenance of information on-line. On the Picture Arrangement Test, individuals are presented with pictures that have to be rearranged to make a story. On the Sentence Arrangement Test, individuals rearrange cards with words on them to make a complete sentence. These tests are purported to measure cognitive sequencing ability, for nonverbal and verbal information respectively.

Only the Picture Arrangement test has been specifically tested on patients with frontal lobe damage. McFie & Thompson (1972) found that patients with right hemisphere damage had significantly poorer scores than patients with left hemisphere damage. The right hemisphere frontal patients performed quite poorly because they left the pictures in the original order. That is, they had a tendency to judge sequences as correct without actually changing the mixed up order in which they originally saw the pictures. This preference to leave cards in original order was replicated by Walsh (1987, p. 154). In addition, Cooper, Sagar, Jordan, Harvey, & Sullivan (1991) found the same trend in patients with Parkinson's disease. The Sentence Arrangement test was designed as a verbal analogue to the Picture Arrangement test, but little data are available about this test with specific neuropsychological populations.

The Stroop test (Stroop, 1935) is another neuropsychological test that has been associated with frontal lobe function, although it does not require holding information in mind as in typical working memory tasks. This test has been considered to provide a measure of the ability to inhibit information. Trenerry, Crosson, DeBoe, and Leber (1989) developed the Stroop Neuropsychological Screening Test so that examiners could screen for inhibition deficits due to brain damage. On the Stroop Test, participants name the colors of ink in which various color names are written. Ink colors either match the color names or they are different. When colors and color names mismatch, people must inhibit the reading of the color name and say the color of the ink in which the word is printed. The number of correct responses within 120 s is the measure of interest.

There has been considerable evidence that the Stroop test is associated with frontal lobe function, but the specific prefrontal area that mediates performance is still unclear. Bench et al. (1993) demonstrated that normal participants completing the Stroop test showed increased PET activation in the anterior regions of the right hemisphere, specifically in orbitomedial areas, anterior cingulate areas, and polar areas of the frontal lobes. In contrast, Richer et al. (1993) found that patients with surgical excisions of the right dorsomedial frontal lobe performed particularly poorly on a Stroop task. Many of these patients had removals of both cingulate and polar frontal cortex as well. In contrast, Vendrell et al. (1995) found that patients with lesions of either lateral prefrontal cortex, specifically Brodmann's area 9, consistently showed naming errors. They found that some patients with extensive frontal lobe damage and others with specific orbitofrontal damage were unimpaired on the task. Vendrell et al. (1995) gave only 24 trials (four blocks of six stimuli each) in which the color and color name were different. Thus, they may have found more impairment if their task had been more difficult. Nevertheless, almost all areas of the frontal lobes have been implicated in the Stroop task, and it is possible that the task specifically measures polar or cingulate areas.

Because frontal lobes appear to be particularly susceptible to the aging process, one might expect that older adults would show particular deficits on frontal lobe tasks. However, areas in the medial temporal lobe region have also been found to be susceptible to aging. Accordingly, memory deficits are also frequently associated with aging. The extent to which these two kinds of deficits co-occur among older adults is as yet unknown. A study that has attempted to explore the differential aging of frontal function and medial temporal function was conducted by Glisky, Polster, & Routhieaux (1995). They conducted a factor analysis of neuropsychological test performance of a group of older adults on tests purported to measure prefrontal function and medial temporal lobe function after partialing out variance associated with age. The factor analysis revealed two independent factors explaining over 99% of the variance on the tests. Tests loading on the frontal factor included the Modified Wisconsin Card Sort Test (number of categories achieved) (Hart et al., 1988), the Arithmetic Subtest of the WAIS-R, the FAS test, and the WMS-R Mental Control and Digits Backwards Subtests. Tests loading on the medial temporal factor included the WMS-R Logical Memory I, Verbal Paired Associates I, and Visual Paired Associates II Subtests and the California Verbal Learning Test Long Delay Cued Recall score (CVLT; Delis, Kramer, Kaplan, & Ober, 1987). From these tests, Glisky et al. (1995) generated two z-scores (i.e. factor scores) for each participant that represented their age independent performance on the frontal tasks and the medial temporal lobe tasks relative to the overall group mean. They found that performance on a source memory test was dependent upon the frontal factor score but not the medial temporal factor score. Conversely, IM performance was dependent on the medial temporal but not frontal factor score. This methodology provides an alternative way to study functions associated with different brain areas without the difficulties associated with researching neurologically impaired patients. A similar procedure might also be used to measure the relative contributions of prefrontal and medial temporal lobe function to TOM and IM.

Cognitive Neuropsychological Theories of Temporal Order Memory

Most researchers have agreed that the frontal lobes play a significant role in the judgement of recency. However, they have proposed several different mechanisms to explain memory for order. Many theories have suggested that one or more of the following functions of the frontal lobes is involved: storage and maintenance of information on line (e.g. Baddeley, 1986; Goldman-Rakic, 1995; Swartz, Halgren, Fuster & Mandelkern, 1994); strategic encoding and retrieval (e.g. Bondi et al., 1993; Moscovitch & Winocur, 1995; Petrides, 1995); and inhibiting extraneous or prepotent alternatives (e.g. Shimamura, 1995; Shallice & Burgess, 1991)[1]. Evidence for these functions, as well as the proposed loci for them, are reviewed below.

<u>Working Memory: Storage of Information</u>

The dorsolateral prefrontal cortex has been consistently implicated in tasks that involve the ability to hold information in mind, and to monitor and manipulate it. Swartz et al. (1994) observed that individuals completing a delayed match to sample test showed increased dorsolateral prefrontal cortical activation via PET. On this task, the critical feature was that participants held stimuli in mind over a delay in order to respond to it at a later time. Deficits on delay tasks have also been consistently observed in lesion studies of nonhuman primates (Goldman-Rakic, 1987; Goldman & Rosvold, 1970). In addition, research has shown that specific cells in the dorsolateral prefrontal cortex fire only during delays between study and test when an item to be remembered is not present in the environment (Fuster, 1991; Fuster & Alexander, 1971; Quintana & Fuster, 1992).

Sagar and his colleagues have proposed that the immediate registration of information, manipulation of independent memoranda, and ability to hold information "on

---

[1]Other theorists (e.g. Schacter, 1987; Milner et al., 1991) have proposed that the frontal lobes contribute to TOM by automatically encoding temporal information. This theory is not tested in this dissertation, so it is not reviewed here. Therefore, the reader is referred to the above articles.

line" (they call it short-term memory) are necessary for TOM success (Cooper et al., 1993; Sagar, Cohen, Sullivan, Corkin, & Growdon, 1988). Sagar et al. (1988) observed that patients with Parkinson's disease have impaired recency discrimination on the verbal continuous TOM task at the shortest retention intervals. That is, Parkinson's disease patients were impaired at judging recency even when no delay occurred between the most recent item and the test of recency. Information at such brief delays, according to working memory theory, should be processed in the articulatory loop. Thus, impairment at the briefest delays supports a hypothesis that the articulatory loop is somehow compromised. Evidence that the manipulation of information in mind, i.e. the central executive, is also compromised came from the fact that Parkinson's disease patients were impaired at all delays, including long delays, compared to both mildly demented Alzheimer's disease patients and normal controls. Parkinson's disease patients were also impaired both overall and specifically at the most recent intervals on a nonverbal analogue of the continuous temporal ordering task. In addition, a patient with unilateral symptoms affecting the left side (i.e. right hemisphere compromise) was differentially impaired on the nonverbal task (Sullivan & Sagar, 1989). These findings imply that discrete frontal lobe systems may be responsible for dysfunction in the genesis of these deficits. Whether the frontal lobes are material-specific, however, is still unclear.

Working memory explanations of TOM have been based on tasks that rely primarily on primary memory. According to Tulving & Colotla (1970), primary memory is used when a lag of less than seven intervening items exists between study and test. Secondary memory is used when the lag is greater than seven items. This distinction is important, because retrieval from primary and secondary memory may involve different processes. Counter to a working memory explanation, patients with frontal lobe lesions have been observed to have deficits on list discrimination tests on which test-pairs were in secondary memory (Butters, Kaszniak, Glisky, Eslinger & Schacter, 1994). In addition, the continuous memory paradigms used have both primary and secondary memory components. Whether decreased TOM performance in patients with frontal lobe lesions is due to impaired primary or secondary memory for temporal information has yet to be explicitly tested. Performance on the continuous memory tasks has rarely been correlated with neuropsychological measures that demand the storage and processing of information on-line. The strength of these correlations may provide indirect evidence of the role of primary memory in recency judgements. In addition, creation of a test that measures TOM only for information in secondary memory (i.e. <u>no</u> primary memory components) would allow researchers to assess other possible mechanisms proposed to be associated with TOM. In addition, such a test should not correlate with measures of primary memory.

<u>Working Memory: Strategic Processing</u>

As mentioned above, Baddeley has proposed that the central executive may be a collection of mechanisms that manipulate on-line information. Several researchers have proposed that the frontal lobes are necessary for strategically encoding and retrieving information in a particular spatio-temporal context. That is, the frontal lobes strategically associate an event with the time and place that it occurred. Moscovitch and Winocur (1995; Moscovitch, 1994; Winocur, 1992) have hypothesized that the prefrontal cortex "works with memory". According to this theory, the hippocampus is modular and automatically encodes information to which one consciously attends. The frontal lobes monitor and implement active strategies to facilitate encoding and retrieval of the hippocampal memories. They make inferences based on memory, temporally order memories, place memories in their appropriate contexts, and select from a variety of responses based on strategic processing. Thus the frontal lobes "work with memory".

Several lines of evidence have supported the role of the frontal lobes in strategy use. First, animals with prefrontal lesions have been unable to learn conditional discrimination tasks, in which they must learn a rule to perform appropriately (If stimulus A, then response X; if stimulus B, then response Y), even with no delay at all (Winocur, 1992). Patients with Parkinson's disease have also shown impairments in conditional associative learning, which were correlated with TOM performance (Vriezen & Moscovitch, 1990). Second, patients with anterior lesions have been more impaired than patients with posterior lesions in learning block tapping sequences <u>only</u> when participants had to create their own strategy to learn the sequence (Vilkki & Holst, 1989). Third, patients with prefrontal lesions and Parkinson's disease patients have performed normally on item recognition memory tasks but been impaired on free recall tasks, which require more strategic processing for accurate performance (e.g. Taylor, Saint-Cyr & Lang, 1986; Janowski, Shimamura, Kritchevsky & Squire, 1989). Fourth, patients with prefrontal lesions and aging individuals have been shown to be impaired on neuropsychological tests that involve strategic functions, such as the Wisconsin Card Sorting Test, FAS Test, and WAIS-R Picture Arrangement Test. Patients with Parkinson's disease have shown similar impairments (e.g. Bondi et al., 1993). Fifth, Naveh-Benjamin (1990) found that teaching participants a strategy improved TOM performance. Thus, if patients can improve their performance by applying a strategy, the task does not rely solely on an automatic process.

Kesner and colleagues (Kesner, 1993; Kesner & Holbrook, 1987) have proposed that the medial prefrontal cortex in rats is associated specifically with strategies that involve temporal information. Rats with prefrontal lesions could not order their actions on a radial arm maze when correct order resulted in reward, even when only two actions were involved. IM was not impaired, i.e. memory for which arms were visited. Kesner (1993) also found that rats with medial prefrontal lesions could not use a temporal strategy to perform well on a four-item paired-associate task. Rats were trained to know that each of four types of sweetened cereal was associated with a particular orienting response (N, S, E, W). The correct pairings never changed, although the order of the four pairs varied across trials. Rats with prefrontal lesions performed progressively worse on each pair within a trial, indicating that they could not use previous information to improve performance (a temporal strategy). These rats, however, performed significantly above chance on the first pair within each trial, indicating that they had intact IM for the pairings. Rats with hippocampal lesions had chance performance on the first two pairings within a trial. However, they showed that they could use a temporal strategy, because they did not pick the answer that immediately preceded the pair in question. That is, they knew that the answers would not repeat themselves during the trial. Thus, rats with medial temporal lobe lesions could benefit from previous trials that they remembered.

Petrides (1995) has suggested that when planning and intention are involved, encoding and retrieval operations are localized in the ventrolateral prefrontal cortex. In contrast, he suggested that, in line with Goldman-Rakic (1995), the dorsolateral prefrontal cortex is specialized for on-line maintenance and manipulation of information. That is, dorsolateral prefrontal cortex has been associated with tasks on which multiple stimuli must be compared simultaneously for a decision to be made (e.g. Petrides, 1994). He has based this notion on PET studies in which strategic retrieval was added to a control condition. When this manipulation was introduced, strategic retrieval from secondary memory activated ventrolateral frontal cortex (Petrides, 1995). Recent PET research from Tulving's lab has also implicated the frontal lobes during strategic encoding and retrieval of information from memory (Tulving et al., 1994).

Sagar and his colleagues (Sagar et al., 1988; Sullivan and Sagar, 1989) have suggested that a specific deficit in sequencing strategy may be impaired as a result of damage to the frontal lobes. He has cited evidence of impaired dating ability in patients with Parkinson's disease. In addition, he has used the impairment of these patients on several TOM tasks as evidence (e.g. Cooper et al., 1993; Sagar, et al. 1988).

A strategy explanation of TOM performance makes certain predictions. First, TOM performance should be correlated specifically with tests that require the development and use of a strategic plan such as the WCST and the FAS Test. Second, if deficits in recency judgments are related specifically to cognitive sequencing deficits, there should be correlations between TOM performance and the Picture and Sentence Arrangement Subtests of the WAIS-RNI. Finally, correlations between neuropsychological measures and TOM tests should still be significant when primary memory demands have been minimized, because strategic ability should be unrelated to primary memory. To test this latter prediction, a TOM test that only measures information in secondary memory should be compared to a test that relies on primary memory only. These hypotheses have yet to be tested.

Working Memory: Inhibition of Responses

Several theorists have proposed that the frontal lobes inhibit inappropriate, unwanted or prepotent responses.

Shimamura (1995) has hypothesized that impairments in memory due to frontal lobe deficits are related specifically to an inability to inhibit extraneous information during information processing. According to Shimamura, the prefrontal cortex filters out extraneous neural processing from posterior cortical areas, with different areas of the prefrontal cortex being responsible for different posterior areas. PET evidence has shown that prefrontal cortical activation is associated with decreases in the activation of posterior areas (Frith et al., 1991). Research using event related potentials to measure electrophysiological activity has also shown that lesions to the frontal lobes lead to disinhibited brain activity in the primary auditory cortex (Knight, Scabini, & Woods, 1989). Shimamura has proposed that deficits are most severe on tasks that depend heavily on self-initiated encoding, organization, and retrieval strategies, because there are more opportunities for interference from nonessential processes/information. Impairments in free recall and FAS tests have occurred in patients with frontal lobe lesions because there is increased competition for possible responses. He has also suggested that retrieval processes are impaired in patients with prefrontal cortical lesions because they show impairments on free recall but not on recognition of autobiographical memories acquired well before the onset of the injury (Shimamura, 1995).

According to Fuster (1985; 1995), the orbitomedial prefrontal cortex is responsible for inhibiting competing, inappropriate and untimely alternatives on cognitive tasks. Lesion data and single cell recordings from this brain region have been associated with inhibition of previous responses (Fuster, 1985; Fuster, 1991). Milner (1982) has also suggested that inhibitory functions are necessary mechanisms for successful encoding of temporal order information, but she has suggested that inhibition is related to dorsolateral prefrontal cortex. Cognitive functions related to the orbitomedial frontal lobes have rarely been studied, because this brain area is most often associated with personality change (e.g. Malloy & Duffy, 1992). However, inhibition ability, presumably related to orbitomedial frontal function may have direct relevance to the understanding of TOM. If inhibition is necessary for the processing of recency judgements, then measures such as the Stroop test should correlate with TOM performance regardless of whether TOM for information in primary or secondary memory is assessed.

Theoretical perspectives on the nature of TOM are quite varied, and the actual mechanism(s) involved are still a matter of debate. Some researchers suggest that the holding of information in mind is crucial to temporal order memory, and most suggest that other cognitive systems or processes are also involved, including mechanisms to inhibit alternatives or generate efficient strategies. Tests of these theories, which measure the relative contributions of these mechanisms to temporal order memory, will be helpful for reaching conclusions concerning the actual mechanisms mediating TOM.

Summary and Proposal

TOM is believed to be dependent on functional mechanisms associated with the frontal lobes. It appears to decline with age to a greater extent than IM, although its relationship to IM in older participants is only beginning to be assessed. In addition, TOM for nonverbal information has yet to be tested in the elderly and compared to verbal TOM. Studying patterns of age-related IM and TOM changes may shed light on theories suggesting differential frontal lobe decline versus differential right hemisphere decline. TOM and IM have yet to be reliably doubly dissociated, and the laterality of TOM is not yet fully understood.

Much debate concerns the cognitive mechanisms underlying TOM performance. Evidence supports roles for simultaneous holding and processing of information in mind, encoding and retrieval strategies, cognitive sequencing, and inhibiting prepotent alternatives. Because the continuous memory tasks place such large demands on the holding and processing of information on-line, the roles of other cognitive mechanisms may not be detectable in these paradigms. In addition, the relationship between primary and secondary memory for temporal information has yet to be addressed.

In order to address these issues, two types of tests were administered to young and older participants. The first type, continuous memory tests, were given, because these tests are the most commonly used with neurologically impaired patients. The continuous TOM tests unconfound retention interval and lag by measuring the same lags at each retention interval. Retention intervals and lags were chosen so that two, one or zero items are in primary memory. In this way, the relative contributions of primary and secondary memory to TOM may be assessed. Both verbal and nonverbal IM and TOM were also be measured such that laterality effects may be evaluated.

A second type of IM/TOM tests, called <u>dis</u>continuous memory tests, was also given. Discontinuous tests are designed to remove effects of working memory in general and primary memory in particular. Rather than alternating between study and test items, which requires constant changing of strategies (e.g. should I encode or retrieve now? What should I retrieve?), memory tests were be conducted at the end of a study list. IM and TOM were assessed separately, and participants were told what type of memory test to expect, so that they could choose a strategy and stick with it. In addition, there was a delay between study and test so that all items would be in secondary memory. The continuous and discontinuous tests had similar instructions, and both a verbal and nonverbal analogue were administered.

For each type of test, the proposed experiment addresses four issues related to TOM. First, the experiment attempts to replicate and extend the finding of decline in TOM as a function of age, both for verbal and nonverbal information. The experiment also measures verbal and nonverbal IM, such that differences in the two kinds of memory may be elicited. The experiment directly compares the hypothesis suggesting greater anterior than posterior decline to the hypothesis suggesting greater right hemisphere than left hemisphere decline by studying verbal and nonverbal IM and TOM together. If older participants perform more poorly on TOM tests than IM tests, then the hypothesis of differential anterior decline were supported. If they show reduced performance only on nonverbal tasks, then the laterality hypothesis would be supported. Interactions between type of test and test material are also possible.

Second, the experiment attempts to find a double dissociation between TOM and IM by using Glisky et al.'s (1995) factor score methodology. Patterns of performance for both the verbal and nonverbal paradigms were inspected for double dissociations, with the frontal factor scores hypothesized to predict TOM and the medial temporal factor scores hypothesized to predict IM. If the frontal factor scores predict performance for only one type of stimuli (verbal vs. nonverbal), then independence of the hemispheres in the processing of these two types of information would be supported.

Third, the experiment attempts to identify the roles of primary and secondary memory in TOM. Continuous memory tests were analyzed by the number of items in primary memory and secondary memory. If the frontal lobe mechanisms underlying TOM are related to primary memory, then the frontal factor scores may predict performance of those test items that are in primary but not secondary memory. In addition, frontal factor score should not predict performance on the discontinuous tests, which only have secondary memory components.

Finally, the experiment attempts to find correlational support for other mechanisms proposed to affect TOM. The Stroop Neuropsychological Screening Test was given in a preliminary attempt to measure the relationships between inhibition and TOM. The WAIS-R Picture and WAIS-RNI Sentence Arrangement subtests, purported to measure nonverbal and verbal cognitive sequencing, respectively, were given in order to generate support for Sullivan and Sagar's (1989) theory that TOM is mediated by cognitive sequencing. Those tests with a strategic component (WCST and FAS) were correlated with TOM. Patterns of correlations between the neuropsychological measures and the continuous and discontinuous experimental tasks were observed. If the neuropsychological tests correlate significantly with the continuous but not discontinuous tests, then working memory explanations of TOM would explain the method by which temporal order is assessed rather than the construct of temporal order memory per se.

CHAPTER 2 - METHOD

Participants

Thirty-two young adults recruited from the introductory psychology pool at the University of Arizona participated for experimental credit. Only individuals with no history of neurological injury, learning disability, alcohol/substance abuse, or current symptoms of depression participated. Only participants who performed in the normal range on the Facial Recognition Test (Benton, 1978), indicating normal complex visuospatial functioning, were allowed to participate.

A total of 32 adults aged 65 or older (range: 65 - 86) participated. Older participants were paid $5.00 per hour. Each participant had initial neuropsychological testing according to Glisky et. al's (1995) factor score generation procedure, so that they could be categorized as being above or below the mean on frontal abilities and medial temporal abilities. One subgroup (8 participants) was comprised of individuals above the mean on both the frontal and medial temporal factor scores (HiF, HiMTL). The second subgroup (7 participants) was above the mean for frontal scores but below the mean on the medial temporal factor (HiF, LoMTL). The third subgroup (8 participants) had the opposite characteristics to the second group (LoF, HiMTL). The fourth subgroup (9 participants) was below the mean on both factor scores (LoF, LoMTL).

Characteristics of the older participants are presented in Table 1. Separate 2 X 2 ANOVAS with frontal status (Hi v. Lo) and medial temporal status (Hi v. Lo) were conducted for each demographic variable, frontal score, and medial temporal score. There was no effect of frontal or medial temporal status on any of the demographic variables (all *p*s > .05). There was a main effect of frontal status on frontal score, with the hi frontal groups having a higher frontal score than the lo frontal groups [$F(3, 28) = 51.35$, $p < .0001$]. Frontal status did not predict temporal score. Nor was there an interaction between frontal and temporal score. Likewise, there was a main effect of temporal status on temporal score, with the hi MTL groups having higher temporal scores than the lo MTL groups [$F(3, 28) = 50.93$, $p < .0001$]. Again, temporal status was unrelated to frontal score, and no significant interaction between frontal and temporal status.

Table 1

Characteristics of older participants. (Standard deviations are in parentheses).

Group	n	F Score	MTL Score	Age	Education	MMSE	Vocab
Hi F/High MTL	8	0.59	0.59	71.38	14.25	28.88	63.63
		(0.58)	(0.35)	(4.75)	(2.05)	(1.13)	(2.56)
Hi F/Low MTL	7	0.53	-0.66	69.57	14.00	28.71	61.57
		(0.35)	(0.51)	(4.50)	(3.36)	(1.38)	(5.44)
Low F/High MTL	8	-0.50	0.37	73.50	15.25	28.13	61.25
		(0.29)	(0.28)	(6.61)	(2.31)	(1.13)	(7.25)
Low F/Low MTL	9	-0.51	-0.51	73.56	14.11	28.78	56.78
		(0.40)	(0.49)	(5.90)	(1.76)	(0.97)	(5.47)

Note. F = Frontal status; FScore = Frontal factor score; MTL = Medial temporal status; MTLScore = Medial temporal factor score; MMSE = Folstein Minimental Status Exam (Folstein, Folstein, & McHugh, 1975); Vocab = Raw score from WAIS-R Vocabulary Subtest. Education = # years completed.

Materials

Verbal stimuli. Nouns with a frequency of 25 per million or more (Kucera and Francis, 1967) were used as stimuli for the verbal tasks (This requirement was used in past research, e.g. Bondi et al., 1993; Milner et al., 1991). These nouns were presented on a Macintosh computer in 20 pt. font to increase ease of readability. Nouns were not used if they could also be interpreted as verbs (e.g. bear) or other parts of speech.

Nonverbal stimuli. Black and white photographs of unfamiliar faces were used as nonverbal stimuli. Each picture measured 2 X 3 in. Pictures were taken from high school and college yearbooks. Equal numbers of male and female photographs were used in each condition. Most pictures were of teachers and school staff and were of people who appeared to be middle aged (ages 35 to 55). Pictures were scanned into a Macintosh computer and all jewelry and bold patterns on clothing were removed.

Procedure

Verbal continuous memory tests. Participants viewed stimuli centered on the computer screen and were instructed to remember both the actual stimuli they studied and the order in which they were presented. Each study word was presented for three seconds. After four primacy items and six study items, two-alternative forced-choice (2AFC) testing began, interspersed with studying, in a predetermined fixed order. On the IM test, participants viewed two stimuli presented simultaneously on the computer screen, one old and one new. They were asked to press a button corresponding to the stimulus they studied. On the TOM test, participants viewed two old stimuli on the computer and pressed a button corresponding to the stimulus they saw first. Tests were structured such that each stimulus had an equal chance of being tested in TOM or IM format. Half of the target stimuli appeared on the left hand side of the computer screen and the other half appeared on the right. If the correct item was on the left, participants pressed a button on the left side of the computer screen (the "1" key). Correspondingly, if the correct item was on the right, they pressed a button on the right side of the computer screen (the "0" key). Participants were told to respond as quickly as they could to test items; otherwise, this was a self paced task.

IM was tested for items presented immediately before the test (i.e., 1 back), or 3, 5, 7, . . . 29 items back. There were thus 15 different lags. For the TOM test pairs, the most recent item occurred 1, 3, 5, 7, or 9 items before the test, and there were either 0, 3, or 9 items intervening between the two test items. These lags were used in order to assess effects of having one or both items in primary v.

secondary memory at the time of test. Four test pairs were used at each IM and TOM interval. Thus, each test had 60 test pairs. Testing occurred in a predetermined fixed order such that no interval was repeated until all other intervals had been tested. Four items were presented at the beginning of the task in order to reduce primacy effects. These items were not tested. In addition, eight untested items were studied such that the desired lags could be obtained. A total of 312 trials were given (188 study trials, 120 test trials, 4 primacy trials). The test took approximately 20 minutes to complete.

A practice trial was given at the beginning of each procedure to ensure that each participant understood the task and pressed the computer keys appropriately (Some older participants pressed the computer keys either too hard or for too long, causing the computer to present items too rapidly). The practice trial was repeated until the participant achieved 100% test performance or verbally explained the task back to the examiner.

<u>Nonverbal continuous memory tests.</u> Milner et al. (1991) found that nonverbal tasks were more difficult than verbal ones. Therefore, in an attempt to equate the verbal and nonverbal continuous tasks, nonverbal stimuli were presented for twice as long as verbal stimuli (6 s per item). Only two test-pairs were given for each item and

order interval due to constraints in finding appropriate nonverbal stimuli. Thus, both the IM and TOM tests had 30 test pairs. Because of limits in computer memory, the continuous tasks had to be divided into three equal blocks, with 10 IM and 10 TOM test-pairs interspersed between study items. For each of these three tasks, four faces were presented at the beginning to absorb primacy effects. These were not tested. Also untested were seven study items strategically placed so that desired lags could be maintained. Thus, a total of 97 study items, 12 primacy items, and 60 test pairs were administered. Participants completed the task in approximately 30 min. Instructions for both the verbal and nonverbal continuous tests are presented in Appendix A.

Verbal discontinuous memory tests. These tasks were created to minimize primary memory and on-line processing/manipulation demands that could be dependent on working memory function. As with the continuous tasks, participants were given a practice test to ensure that they understood instructions and could press the computer keys appropriately.

Participants completed the IM and TOM tests separately. For both types of tests, participants studied stimuli by stating whether their associations with them were pleasant or not pleasant. Depending on the test that would follow, they were told to remember either the items they studied or the order in which the items were studied. Stimuli were presented in a predetermined random order. Following study, participants were asked to count backwards for a predetermined amount of time in order to eliminate recency effects. Then testing occurred in a 2AFC format. Half of the target items appeared on the left side of the screen. The other half appeared on the right. As with the continuous tasks, participants responded by pressing the "1" key or "0" key depending on which side of the screen the target answer was presented. Participants responded as quickly as they could.

For the IM task, participants studied 104 nouns presented at a rate of 3 s per item. The first four items were not tested, as they were used to eliminate primacy effects, leaving a total of 100 items for test. After studying the items, participants counted backwards from 500 for 3 min. Then, they saw pairs of items, only one of which was previously studied, and were asked to press the computer key corresponding to it.

For the TOM task, participants completed four study/test blocks, each with 14 stimuli. Participants studied each stimulus for 4.5 seconds. After each study phase, participants were asked to count backwards from 500 for 25 s in order to reduce recency effects. Following the counting distractor task, participants were shown pairs of words they had studied and were asked to press a computer key corresponding to the word they studied first. Twenty-four test pairs were created such that one item came from the first half of the list and the other came from the second half of the list. This pairing resulted in one test pair for lags = 1, 9, and 10, two test pairs for lag = 6, three test pairs for lags = 7 and 8, four test pairs for lag = 3 and 4, and five test pairs for lag = 2. For each block, the first two items studied were not tested in order to reduce primacy effects. Thus, a total of 24 pairs of words were tested.

<u>Nonverbal discontinuous memory tests.</u> In order to equate difficulty of the verbal and nonverbal discontinuous tasks, several minor alterations were made to the method. Except for the following alterations, the nonverbal discontinuous tasks were identical to their verbal counterparts. For the nonverbal discontinuous IM task, participants studied only 50 faces (plus 4 faces at the beginning to reduce primacy effects) for 6 s each (rather than 100 for 3 s each). Participants did not count backwards for a distractor. Rather, a new program had to be loaded into the computer's memory, which took approximately 2 min. There was also a short break (approximately 2 minutes) after half of the test pairs had been presented in

order for the computer to load the faces required for the second half of the test. For the nonverbal discontinuous TOM task, participants studied 4 blocks of 14 items for 6 s each. Participants counted backwards from 500 for 20 s. Lags for this test were as follows: one test pair for lags = 1 and 10, two test pairs for lags = 2, 3, 7, and 8, three test pairs for lag = 6, four test pairs for lag = 4, and seven test pairs for lag = 5. Instructions for the discontinuous tasks are presented in Appendix B.

Neuropsychological tests. In addition to the four tests of IM and TOM generated above, several neuropsychological tests were administered. The WAIS-RNI Sentence and Picture Arrangement subtests were administered in order to measure participants' verbal and nonverbal sequencing, respectively. For both tests, sequencing ability was measured by giving credit for each card that was sequenced correctly. Total stories/sentences correct were also measured. The Stroop Neuropsychological Screening Test was administered because this test has been proposed to be associated with inhibition of prepotent alternatives. Number of correct incongruent responses within 120 s was the dependent measure. The Geriatric Depression Scale (GDS; Yesavage et al., 1983) was administered to the older participants and the Beck Depression Inventory (BDI; Beck, 1987) was administered to the young participants in order to rule out the possibility of a depressive affective disorder. The GDS was chosen to measure elderly participants' affect, because it does not include somatic complaints that could be misinterpreted as depressive symptomatology. The young participants also completed the WAIS-R Digit Span subtest in order to get a measure of their working memory. All neuropsychological tests were administered according to their standardized administration instructions.

Testing sessions lasted between one and two hours each. Verbal tests were completed on one day and nonverbal tests on another. Because the continuous tests combined item and order test-pairs into one task, participants completed discontinuous IM and TOM tests in blocks. Order of the tests was switched across testing sessions, such that if participants completed a discontinuous test first on the first day, they completed the continuous test first on the second day. Order of the IM and TOM discontinuous test was also switched across sessions. This led to eight possible test orders, to which participants were randomly assigned. In order to reduce practice effects among experimental tasks, the tasks were embedded in a neuropsychological test battery. Participants completed all experimental memory tasks, combined with the neuropsychological measures proposed to be related to TOM.

Young and older participants completed slightly different experimental and neuropsychological test orders. Because older participants were part of an ongoing research program, they had already been screened for alcohol or drug abuse or psychiatric history. Young participants, however, had not been previously screened. In addition, in pilot testing, many young participants performed in the mildly depressed range on the BDI and some performed in the impaired range on the Facial Recognition Test because they needed glasses. Therefore, young participants were screened in a separate testing session so that they would not have to spend extra time if they did not qualify to complete the experiment. Thus, older participants completed the procedure in two sessions, while young participants completed it in three. Tests were administered in the following order:

Older Participants:

Day 1:

1. Consent Form
2. Facial Recognition Test
3. Experimental Test 1
4. Geriatric Depression Scale
5. Experimental Test 2
6. WAIS-NI Sentence Arrangement Test

Day 2:

1. WAIS-NI Picture Arrangement
2. Experimental Test 3
3. Stroop Neuropsychological Screening Test
4. Experimental Test 4
5. Debriefing

Young Participants

Screening:

6. Consent Form
7. Screening Interview
8. Facial Recognition Test
9. Beck Depression Inventory

Day 1:

1. WAIS-NI Sentence Arrangement Test
2. Experimental Task 1
3. WAIS-R Digit Span
4. Experimental Test 2

Day 2:

1. WAIS-NI Picture Arrangement Test
2. Experimental Test 3
3. Stroop Neuropsychological Screening Test
4. Experimental Test 4
5. Debriefing

CHAPTER 3 - RESULTS

Rationale and Organization

For ease of exposition, results from the continuous and discontinuous tests are considered separately. For the most part, verbal and nonverbal tests are also considered separately, except when direct comparison is appropriate as when testing hypotheses concerning the locus of age-related effects.

Many analyses of variance were conducted, leading to an increased chance of a Type I error. Therefore, Tukey's HSD tests were used when conducting between subject post-hoc comparisons so that the probability of making a Type I error was kept to a minimum. In addition, a more stringent criterion of significance ($p < .01$) was used when assessing whether correlations were significantly different from zero.

Age-Related Hypotheses

Continuous Memory Tests

To examine age-related differences, a 2 X 2 X 2 mixed design ANOVA was conducted, with age (young adult/older adult) as the between subjects variable, and stimulus type (verbal/nonverbal) and memory type (IM/TOM) as within subjects variables. Table 2 displays age-related changes on the continuous IM and TOM tests.

Table 2

Mean percent correct on continuous memory tests in young and older adults (Standard deviations are in parentheses.)

	Group	
Test Type	Young Adults	Old Adults
Verbal Item Memory	86.56	76.82*
	(8.52)	(10.59)
Nonverbal Item Memory	87.29	88.23
	(9.18)	(7.28)
Verbal Temporal Order Memory	69.69	55.47*
	(8.36)	(9.06)
Nonverbal Temporal Order Memory	72.81	63.23*
	(9.12)	(10.66)

Note. For each group, $\underline{n} = 32$.
$*\underline{p} < .05$

A main effect was observed for age [$\underline{F}(1, 62) = 33.47$, $\underline{p} < .0001$], with young adults outperforming older adults. A main effect was also observed for memory type [$\underline{F}(1, 62) = 349.87$, $\underline{p} < .0001$], with all participants performing better on the IM tests than the TOM tests. A significant interaction between age and memory type [$\underline{F}(1, 62) = 12.85$, $\underline{p} < .001$] indicated that older participants showed a greater decline on the TOM tests than the IM tests when compared with young participants. Simple main effects analyses revealed that the young performed better than the old on both the TOM and IM tests, but there was a greater age-related decline for the TOM tests than the IM tests (MSE = 69.04, HSD = 2.94, $p < .05$). A nondirectional one-sample t test revealed that older adults' TOM performance was greater than a chance level of 50% for all conditions [all ts > 3.41, $p < .005$]. There was a main effect of type of stimulus used, with participants performing better on the tests using faces than those using words [$F(1, 62) = 24.92$, $p < .0001$]. A significant interaction between type of stimuli and age was also observed [$F(1, 62) = 11.18$, $p < .01$]. Analysis of simple main effects revealed that the older participants performed significantly worse than young participants on the tests utilizing words (MSE = 85.06, HSD = 3.26, $p < .05$). No other interactions were significant.

Discontinuous Memory Tests

Age-related changes on discontinuous IM and TOM tests are presented in Table 3. As with the continuous tests, a main effect of age was observed, with young adults performing better than older adults [$F(1, 62) = 28.49$, $p < .0001$]. There was also a main effect of memory type, with participants performing better on the IM tests than TOM tests [$F(1, 62) = 438.43$, $p < .0001$]. The interaction between memory type and age was also significant, indicating that older adults showed a differential decline on the TOM tests compared with the IM tests [$F(1, 62) = 38.62$, $p < .0001$]. Pairwise comparisons between young and old participants revealed an age-related decline on the TOM tests but not the IM tests ($MSE = 77.52$, HSD = 3.11, $p < .05$). One sample nondirectional t tests verified that verbal and nonverbal TOM performance was greater than chance levels of 50% [$t(31) = 3.28$, $p < .005$ and $t(31) = 3.50$, $p < .005$, respectively]. Contrary to the continuous test results, there was no significant main effect of type of stimulus used (words v. faces); nor did the type of stimulus interact with any other variables.

Table 3

Mean percent correct on discontinuous memory tests in young and older adults (Standard deviations are in parentheses)

	Group	
Test Type	Young Adults	Old Adults
Verbal Item Memory	90.91	87.59
	(8.34)	(7.19)
Nonverbal Item Memory	92.25	89.69
	(5.02)	(6.99)
Verbal Temporal Order Memory	73.83	57.42**
	(14.40)	(12.78)
Nonverbal Temporal Order Memory	76.95	60.16**
	(10.90)	(16.39)

**$p < .05$

Hypotheses of Independence of TOM and IM

In order to explore whether frontal or medial temporal functioning in the older participants predicted performance in TOM or IM, separate analyses were conducted for each type of material (Continuous Verbal; Continuous Nonverbal;

Discontinuous Verbal; Discontinuous Nonverbal). For each type of task, a 2 X 2 X 2 mixed design analysis of variance was conducted. Frontal Score (Hi/Lo) and Memory Score (Hi/Lo) were between subjects variables, and type of memory task (TOM/IM) a within subjects variable. Performance on each task is presented below.

Continuous Verbal Tests

Table 4 displays mean performance on the IM and TOM tests broken down by frontal lobe and medial temporal lobe factor scores. The only significant effect was a main effect for memory type, with participants performing better on the IM test than the TOM test [$F(1, 28) = 56.64$, $p < .0001$.] Effects for frontal score ($F = 2.14$) and medial temporal score ($F = 1.32$) were not significant. No significant interactions were observed. Non directional t tests revealed that TOM performance was greater than chance level of 50% only for the high frontal group [$t(14) = 4.76$, $p < .001$] and the high MTL group [$t(16) = 3.15$, $p < .01$). The low frontal group ($t = 1.10$) and the low MTL group ($t = 1.73$) did not perform greater than chance.

Table 4

Mean percent correct on continuous verbal tests broken down by frontal lobe and medial temporal lobe factor scores (Standard deviations are in parentheses)

		Memory Type	
Group	n	Item	Temporal Order
Frontal Factor Score			
High	15	77.00	58.67
		(8.17)	(7.05)
Low	17	76.67	52.65
		(12.61)	(9.88)
MTL Factor Score			
High	16	78.02	56.77
		(10.98)	(8.60)
Low	16	75.63	54.16
		(10.41)	(9.60)

Continuous Nonverbal Tests

Older participants' performance on the continuous nonverbal tests broken down by their frontal and medial temporal scores are presented in Table 5. Results showed a similar pattern to those above: a main effect for test type, with IM performance greater that TOM performance [$F(1, 28) = 198.29$, $p < .0001$], and no main effects for frontal or medial temporal score (Fs = 0.63 and 1.65, respectively). Again, no interactions were significant. All scores were significantly greater than chance.

Table 5

Mean percent correct on continuous nonverbal tests broken down by frontal lobe and medial temporal lobe factor scores (Standard deviations are in parentheses)

		Memory Type	
Group	n	Item	Temporal Order
Frontal Factor Score			
High	15	88.89	64.89
		(6.98)	(10.46)
Low	17	87.65	61.76
		(7.71)	(10.94)
MTL Factor Score			
High	16	90.63	64.38
		(6.23)	(9.09)
Low	16	85.83	62.08
		(7.65)	(12.22)

In order to assess the effect of frontal and medial temporal status on memory for verbal and nonverbal information, two 2 X 2 X 2 mixed design ANOVAs were conducted. For the first ANOVA, frontal status (Hi/Lo) was a between subjects variable, with type of stimulus used (word/face) and type of memory (IM/TOM) as within subjects variables. Significant main effects were found for memory type, with participants performing better on the IM test than the TOM test [$F(1, 30) = 179.56$, $p < .0001$], and type of stimulus, wit participants performing better on the tests with faces than the tests with words [$F(1, 30) = 35.26$, $p < .0001$]. No other main effects were significant. In addition, no differential effects of frontal lobe status were observed between verbal and nonverbal materials ($F = 0.08$).

The second 2 X 2 X 2 ANOVA was identical to the first, except that it replaced frontal lobe status with temporal lobe status (Hi/Lo). Again, the main effect for memory type was significant, with better performance on the IM test than the TOM test [$F(1, 30) = 173.05$, $p < .0001$]. In addition, the main effect for stimulus used was significant, with participants performing better on the tests with faces than words [$F(1, 30) = 35.30$, $p < .0001$]. The main effect for medial temporal lobe score was not significant ($F = 2.74$, $p = .11$). No interactions reached significance.

Discontinuous Verbal Tests

Table 6 illustrates older participants' performance on the discontinuous verbal IM and TOM tests broken down by their frontal and medial temporal scores. Several main effects were observed. Participants performed better on the IM test than the TOM test [$F(1, 28) = 142.98$, $p < .0001$]. Participants who had high frontal factor scores performed better than those with low frontal factor scores [$F(1, 28) = 6.77$, $p < .05$]. Participants who had high medial temporal factor scores performed better than those with low medial temporal factor scores [$F(1, 28) = 4.43$, $p < .05$]. However, participants in the low frontal group and low MTL group performed at chance levels on the TOM test [$t(16) = 1.34$ and $t(15) = 1.44$, respectively]. No interactions were significant.

Because the standard deviations for the TOM tasks were much larger than the standard deviations for the IM tasks, scores for all tasks were standardized (made into z-scores). Another ANOVA with the same independent variables as above was conducted on this standardized data set. The main effects for frontal status and medial temporal status were significant, with participants in the Hi groups performing better than those in the Lo groups [In order, $F(1, 28) = 8.07$, $p < .01$, and $F(1, 28) = 5.29$, $p < .05$]. No significant interactions were found.

Table 6

Mean percent correct on discontinuous verbal tests broken down by frontal lobe and medial temporal lobe factor scores (Standard deviations are in parentheses.)

		Memory Type	
Group	n	Item	Temporal Order
Frontal Factor Score			
High	15	90.40	61.39
		(6.32)	(12.84)
Low	17	85.11	53.92
		(7.16)	(12.01)
MTL Factor Score			
High	16	89.75	60.42
		(5.96)	(12.91)
Low	16	85.44	54.43
		(7.83)	(12.31)

Discontinuous Nonverbal Tests

Older participants' performance on the IM and TOM tests broken down by frontal and medial temporal factor scores are presented in Table 7. A main effect was observed for test type, with performance on the IM test better than performance on the TOM test [$F(1, 28) = 165.06$, $p < .0001$]. A main effect was also observed for medial temporal score, with high medial temporal participants outperforming low medial temporal participants [$F(1, 28) = 5.47$, $p < .05$.]. The low frontal group [$t(16) = 1.59$] and low MTL group [$t(15) = 1.13$] did not perform greater than chance on the TOM test. No other main effects or interactions were significant.

Again, to equate variances across tasks, data from the IM and TOM tests were standardized, and a separate ANOVA was conducted. The only significant main effect was for medial temporal status [$F(1, 28) = 7.01$, $p < .05$]. No other main effects or interactions reached significance.

Table 7

Mean percent correct on discontinuous nonverbal tests broken down by frontal lobe and medial temporal lobe factor scores (Standard deviations are in parentheses.)

		Memory Type	
Group	$\underline{n}$	Item	Temporal Order
Frontal Factor Score			
High	15	90.53	63.89
		(6.98)	(15.72)
Low	17	88.94	56.86
		(7.11)	(16.73)
MTL Factor Score			
High	16	93.00	65.10
		(4.20)	(12.81)
Low	16	86.38	55.21
		(7.74)	(18.42)

As with the continuous memory tests, the effects of frontal and medial temporal status on memory for verbal and nonverbal information was assessed via two 2 X 2 X 2 mixed design ANOVAs were conducted. For the first ANOVA, frontal status (Hi/Lo) was a between subjects variable, with type of stimulus used (word/face) and type of memory (IM/TOM) as within subjects variables. The only significant main effect was found for memory type, with participants performing better on the IM test than the TOM test [$F(1, 30) = 297.39$, $p < .0001$]. A trend was found for frontal score, with the high frontal group outperforming the low frontal group [$F(1, 30) = 4.09$, $p = .05$]. No main effect was found for type of stimulus used ($F = 1.70$), and no differential effects of frontal lobe status were observed between verbal and nonverbal materials ($F = 0.31$).

The second analysis substituted medial temporal status for frontal lobe status as the between subjects variable. The only significant main effects were for memory type, with performance greater on the IM tests than the TOM tests [$F(1, 30) = 290.60$, $p < .001$], and for temporal score, with the high medial temporal group outperforming the low medial temporal group [$F(1, 28) = 7.03$, $p < .05$]. No other main effects or interactions were significant.

Role of Primary Memory in TOM and IM Performance

Continuous verbal and nonverbal test performance was aggregated in order to provide a more reliable assessment of and IM performance as a function of primary versus secondary memory. TOM test pairs were categorized as to whether both items were in primary memory (no more than six items separating study and test), both items were in secondary memory (seven or more items separating the most recent item and the test), or one item was in primary memory and one was in secondary memory. IM test pairs were categorized as to whether the item in question was in primary or secondary memory. Number of items in primary memory, frontal status (high vs. low) and medial temporal status (high vs. low) were then used as independent variables in three-way ANOVAs in order to predict performance on each test.

Results for the continuous TOM test are presented in Table 8. There was a main effect for the number of items in primary memory [$F(2, 27) = 5.34$, $p < .01$]. Comparisons of overall means revealed that participants performed better when one or more test item was in primary memory than when both items were in secondary memory (MSE = 10630.95, HSD = 8.76, $p < .05$). A trend was observed for frontal status, with participants scoring high on the frontal factor performing better than those who scored low on it [$F(1, 28) = 3.76$, $p = .06$]. In addition, the interaction between frontal status and number of items in primary memory was significant [$F(2, 27) = 7.06$, $p < .01$]. Pairwise comparisons revealed that participants scoring high on the frontal factor outperformed those who performed low on it only when one or more item was in primary memory (MSE = 14948.81, HSD = 8.86, $p < .05$, and MSE = 17026.46, HSD = 9.45, respectively). The effect disappeared when both items were in secondary memory. However, nondirectional t tests showed that when both items were in secondary memory, all groups except the low frontal group [$t(16) = 2.75$, $p < .05$] performed at chance levels. In addition, the low frontal group performed at chance levels when one item was in primary memory [$t(16) = 1.91$]. The main effect for medial temporal score and all other interactions were not significant.

Table 8

Mean percent continuous TOM performance as a function of number of test items in primary memory (Standard deviations are in parentheses)

Group	n	Number of Items in Primary Memory		
		Two	One	Zero
Frontal Factor Score				
High	15	66.67	70.00	51.67
		(11.65)	(10.82)	(6.43)
Low	17	57.54	56.90	57.23
		(13.03)	(14.86)	(10.85)
MTL Factor Score				
High	16	65.63	64.22	54.17
		(11.74)	(13.38)	(7.84)
Low	16	58.01	61.88	55.08
		(13.03)	(12.55)	(9.72)

Results for the continuous IM tests are presented in Table 9. A main effect was observed for memory type, with participants performing better on primary memory items than secondary memory items [$F(1, 28) = 13.80$, $p < .001$]. The effects for frontal status ($F = 0.04$) and medial temporal lobe status (F = 2.79) were not significant. No significant interactions were observed.

Table 9

Mean percent correct on continuous item tests broken down by type of memory tested, frontal status and medial temporal status. (Standard deviations are in parentheses.)

		Type of Memory Tested	
Group	n	Primary	Secondary
Frontal Factor Score			
High	15	86.11	82.15
		(8.57)	(6.42)
Low	17	88.73	80.51
		(12.46)	(5.92)
MTL Factor Score			
High	16	90.63	82.75
		(8.91)	(5.90)
Low	16	84.37	79.82
		(12.37)	(6.41)

All items on the discontinuous memory tests were in secondary memory. Thus, discontinuous memory tests results are independent of primary memory, and no analyses need be reported here.

Role of Strategy, Sequencing and Inhibition in TOM

In order to assess the relationship between TOM, strategy, and inhibition, the continuous (high working memory) and discontinuous (low working memory) TOM tests were correlated with WCST Perseverations, FAS, Picture Arrangement, Sentence Arrangement, and the Stroop Neuropsychological Screening instrument. Two types of correlations were analyzed (a) zero-order correlations and (b) semi-partial correlations that partialled out age from the experimental and neuropsychological measures. In this way, age-dependent and age-independent correlations could be inspected. Only correlations with alpha < .01 were considered significant, with alphas < .10 considered trends, because of a large number of correlations were conducted. Results for older and younger participants are presented in Table 10 and Table 11, respectively.

Continuous TOM Tests

For the older participants, on the continuous verbal TOM test, the only significant correlation was with Picture Arrangement Sequencing. This effect became nonsignificant when age-associated variance was partialled out ($p < .05$). No significant correlations were found between the continuous nonverbal TOM test and the experimental variables, regardless of whether age-associated variance was left in or partialled out. No zero-order or semi-partial correlations between any neuropsychological test and either continuous TOM test were significant for the young participants.

Discontinuous TOM Tests

For young and older participants, all zero-order and semi-partial correlations between discontinuous TOM performance and the neuropsychological measures failed to approach significance.

Table 10

Raw and semi-partial correlations between neuropsychological tests and TOM tests: Older participants

	Experimental Test Type			
	Verbal		Nonverbal	
Neuropsych. Test	Cont.	Discont.	Cont.	Discont.
Raw Correlations				
WCST Perseverations	-0.32	0.01	-0.19	-0.08
FAS	0.35	-0.09	0.09	0.02
Stroop # Correct	0.43**	0.10	0.34	0.17
Sentence Arr: Seq.	0.17	0.01	0.37**	0.03
Picture Arr: Seq.	0.54***	0.27	0.34	0.13
Semi-Partial Correlations Residualized for Age				
WCST Perseverations	-0.35	0.01	-0.19	-0.08
FAS	0.22	-0.16	0.04	-0.06
Stroop # Correct	0.30	0.05	0.32	0.13
Sentence Arr: Seq.	0.16	0.01	0.37**	0.03
Picture Arr: Seq.	0.41**	0.24	0.33	0.07

Note. n = 32.
**p < .05; ***p < .01

Table 11

Raw and semi-partial correlations between neuropsychological tests and TOM tests: Young participants

	Experimental Test Type			
	Verbal		Nonverbal	
Neuropsych. Test	Cont.	Discont.	Cont.	Discont.
Raw Correlations				
Stroop # Correct	0.03	-0.00	0.33	0.15
Sentence Arr: Seq.	0.06	-0.13	-0.20	0.24
Picture Arr: Seq.	-0.17	-0.11	-0.32	-0.01
Semi-Partial Correlations Residualized for Age				
Stroop # Correct	0.04	0.01	0.34	0.12
Sentence Arr: Seq.	0.07	-0.12	-0.20	0.20
Picture Arr: Seq.	-0.20	-0.14	-0.33	0.06

Note. n = 32

Retention Interval and Lag Effects

Continuous Memory Tests

Verbal tests. Performance on the continuous TOM tests broken down by retention interval is presented in Table 12. For the TOM test, a 3 X 5 mixed design ANOVA was conducted in order to determine effects of lag (0, 3, or 9 intervening items) and retention interval (most recent item = 1, 3, 5, 7, or 9). A significant effect of retention interval was found [$F(4, 60) = 35.32$, $p < .0001$]. Pairwise comparisons revealed a downward trend as retention interval increased. Performance on items with retention interval = 1 was significantly better than retention interval = 3, which was significantly better than retention interval = 7 (MSE = 1.09, HSD = 11.00, $p < .05$). Performance at retention interval = 5 was in between performance at intervals 3 and 7. Intervals = 7 and 9 did not differ significantly from each other. The main effect of lag and the lag X retention interval interaction were not significant. Separate analyses with participants grouped by age revealed the same results: a decreasing performance as retention interval increased and no effect of lag.

Table 12

Mean performance on the continuous TOM tasks classified by retention interval (Standard deviations are in parentheses)

	Retention Interval					
Continuous Test	1	3	5	7	9	Total
Verbal	82.81	66.67	56.38	51.82	55.20	62.58
	(20.02)	(21.00)	(13.34)	(16.36)	(15.75)	(11.23)
Nonverbal	86.20	74.22	58.59	60.68	60.42	68.02
	(21.11)	(16.78)	(20.57)	(20.44)	(16.40)	(10.96)

Mean performance on the continuous IM tests broken down by retention interval is presented in Table 13. The effect of retention interval was measured for verbal IM by classifying interval as short (1 through 9), medium (11 through 19), and long (21 through 29). A 2 X 3 two-way mixed design ANOVA was conducted with two levels of age (young/old) and three levels of retention interval. Results revealed a main effect for age, with young participants outperforming older participants [$F(1, 62) = 16.89$, $p < .0001$]. In addition, the main effect for retention interval was significant [$F(2, 62) = 35.23$, $p < .001$]. Pairwise comparisons documented that IM was better for the short retention interval than either the medium or long retention intervals ($MSE = 2.77$, HSD = 4.78, $p < .01$). The interaction between age and retention interval was not significant.

Table 13

Mean performance on the continuous IM tasks classified by retention interval (Standard deviations are in parentheses)

	Retention Interval			
Continuous Test	Short	Medium	Long	Total
Verbal	89.20	78.20	77.66	81.69
	(9.45)	(14.55)	(13.54)	(10.72)
Nonverbal	90.31	89.38	83.59	87.76
	(10.69)	(11.11)	(13.26)	(8.23)

Nonverbal tests. Mean lag X retention interval continuous nonverbal TOM performance is presented in Table 14. Significant main effects were observed for lag [$F(2, 62) = 23.81$, $p < .001$] and retention interval [$F(4, 60) = 26.51$, $p < .001$]. The lag X retention interval interaction was significant [$F(8, 56) = 7.66$, $p < .001$]. Post-hoc comparisons revealed that generally, lag = 0 was significantly more difficult than lag = 3, which did not differ significantly from lag = 9. ($MSE = 0.34$, HSD = 12.50, $p < .05$). In addition, performance was equivalent between retention intervals 1 and 3, with a significant decline for retention interval = 5, which did not differ significantly from retention intervals = 7 and 9 (*MSE* = 0.37, HSD = 14.85, $p < .05$). Pairwise comparisons of means showed that for lag = 0, only items with retention interval = 1 were significantly above chance. At lags = 3 performance was better for retention intervals = 1 and 3 than the three longer intervals. At lag = 9, performance declined to chance levels by interval = 7, but performance improved at interval = 9. Thus, the best performance was at the shortest retention intervals with the lags greater than one, and at the longest interval with the longest lag. Separate ANOVAs for young and older participants revealed the same pattern of performance, so for ease of exposition, group data were collapsed.

Table 14

Mean performance on the nonverbal continuous TOM tasks classified by lag and retention interval (Standard deviations are in parentheses)

	Retention Interval					
Lag	1	3	5	7	9	Total
0	89.85	51.55[a]	45.31[a]	54.70[a]	51.55[a]	58.59
	(20.28)	(33.30)	(35.32)	(31.77)	(33.30)	(14.89)
3	85.15	86.70	64.85	69.55	57.82[a]	72.81
	(27.72)	(25.58)	(30.45)	(34.06)	(33.60)	(17.66)
9	83.50	84.38	65.62	57.81[a]	71.88	72.66
	(29.62)	(23.36)	(35.50)	(39.06)	(26.54)	(17.66)

[a]Means are not significantly different from chance.

One-way repeated measures ANOVA documenting the effect of retention interval (short, medium, long) on nonverbal IM performance showed a significant main effect [$F(2, 62) = 2.27$, $p < .01$]. Pairwise comparisons revealed that the short and medium retention intervals did not differ significantly from each other, but they yielded better IM performance than the long retention interval ($MSE = 1.05$, HSD = 5.00, $p < .05$).

Discontinuous TOM Tests

The discontinuous TOM test pairs were created such that one item came from the first half of the list and the other came from the second half. Because these tests were not created to systematically vary lag, each lag was not measured by the same number of test pairs. In addition, because the number of test pairs was quite low for each test, the discontinuous verbal and nonverbal TOM test pairs were aggregated. Lag varied from 1 to 10 intervening items, but lags of 1, 9, and 10 had only one test pair measuring them. For each participant, these three test pairs were not analyzed. For each of the other lags, average percent correct was determined. Because this analysis was exploratory, the more stringent alpha level of .01 was used to measure significance. A one-way repeated measures ANOVA for lag (2, 3, 4, 5, 6, 7, 8) was conducted, and the main effect of lag was significant [$F(6, 58) = 4.19$, $p < .01$].

These data are presented in Table 15. Polynomial contrast revealed that a linear function best characterized the relationship between lag and percent correct [$F(1, 63) = 21.10$, $p < .001$]. Because this analysis was exploratory, only means for the shortest lag and longest lag were compared. Participants performed better on the longest lag than the shortest lag ($MSE = 3.51$, $HSD = 11.43$, $p < .01$].

Table 15

Mean performance on the discontinuous TOM tasks classified by lag (Standard deviations are in parentheses)

	Lag						
	2	3	4	5	6	7	8
M =	58.20	63.67	68.95	67.86	70.90	69.92	72.66
SD =	(21.01)	(23.54)	(19.42)	(23.60)	(24.44)	(21.13)	(23.31)

Practice Effects

Continuous Memory Tests

In order to rule out the possibility that participants were learning strategies to increase their performance over time, each test was broken down into two parts and totals for each half were calculated. Total correct for each test was analyzed as a function of half in a one-way repeated measures ANOVA with half (first, second) as the independent variable. A main effect of half was found for the verbal TOM test [$F(1, 63) = 9.87$, $p < .01$] and the verbal IM test [$F[1, 63) = 37.81$, $p < .0001$]. However, participants performed better on the first half than the second half of both the TOM test ($M = 65.13$, $SD = 12.63$ and $M = 60.20$, $SD = 13.07$ respectively) and IM test ($M = 85.83$, $SD = 10.87$ and $M = 77.80$, $SD = 12.60$ respectively).

Practice effects were assessed slightly differently for the continuous nonverbal tests. Because these tests were created such that each test had three sections of 10 test pairs, a one-way repeated measures ANOVA was conducted for each test, with three levels (first, second, third) of practice. Unlike their verbal counterpart, there were no effects of practice for the continuous nonverbal TOM test and the IM test ($Fs = 0.34$ and 1.09 respectively).

Discontinuous Memory Tests

IM tests. Average performance on the verbal and nonverbal discontinuous IM tests was calculated as a function of half. For each IM test, a one-way repeated measures ANOVA was conducted with half (first, second) as the independent variable and percent correct as the dependent variable. Main effects indicated that participants' IM performance declined as the test continued for both the verbal test [$F(1, 63) = 5.51$. $p < .05$] and the nonverbal test [$F(1, 63) = 39.41$, $p < .001$].

TOM tests. Because each discontinuous TOM test had four blocks, practice effects were assessed by comparing performance on these blocks over time. For both the verbal and nonverbal TOM test, a one-way repeated measures ANOVA was conducted with fourth (1, 2, 3, 4) as the independent measure and percent correct as the dependent measure. Neither of these analyses produced significant effects.

Correlations Between TOM and IM

Pearson product moment correlations were calculated for performance on all of the experimental TOM tests and their IM counterparts for all participants (N = 64). Continuous verbal TOM and IM were significantly correlated ($r = 0.29$, $p = .01$). Continuous nonverbal, discontinuous verbal and discontinuous nonverbal TOM and IM tests were even more strongly correlated (*r*s = 0.47, 0.47, 0.56 respectively, *p*s < .0001).

CHAPTER 4 - DISCUSSION

This dissertation was designed to address four issues: the theoretical implications age-related changes in TOM and IM, the extent to which TOM and IM are independent and lateralized depending on the stimulus materials, IM, the role of primary and secondary memory in TOM, and the possible roles of sequencing, strategy, and inhibition in TOM. Discussion of each of these issues in light of present findings are presented below, followed by a synthesis of how these issues interact with each other.

Age-Related Hypotheses

Results of the continuous and discontinuous tasks supported the theory that the age-related decline is more pronounced in the frontal lobes than posterior brain structures. Greater age-related decline was observed on the TOM tasks, which are believed to depend on frontal lobe function, than on the IM tasks, which are believed to rely on medial temporal lobe function. In fact, on the discontinuous memory tests, older participants showed no age-related decline on the IM tasks but they showed significant decline on the TOM tasks.

The hypothesis that age-related decline in the right-hemisphere is more pronounced than the left-hemisphere was not supported. On the continuous memory tasks, performance on tests using faces, which are proposed to tap right-hemisphere function, was actually <u>better</u> than performance on tests using words, which tap left-hemisphere function. This finding is the opposite of what a right-hemisphere hypothesis of aging would suggest, as performance on tests using faces should be worse than tests using words. Further, discontinuous IM performance was equivalent across age groups regardless of whether faces or words were used.

It is of interest that older participants performed more poorly on verbal materials than nonverbal materials when completing the continuous memory tasks, whereas young participants performed equally well. Several factors could explain this pattern of performance. First, fatigue may have played a role. The continuous verbal test had twice as many items as its nonverbal counterpart. On the continuous verbal tests, participants' performance on the first half was higher than performance on the second half. On the TOM task, performance declined an average of 5% on the second half of the test; on the IM task, performance was 7% lower on the second half.

It is unlikely that fatigue played a strong role in the greater decline on the continuous tests that used words. Performance on the first half of the continuous verbal tests, when participants were not fatigued, showed the same overall pattern as total performance: decline on the item memory test and larger decline on the verbal TOM test than the nonverbal TOM test.

Second, it is possible that participants showed a greater age-related decline on the verbal tests because they were more difficult than the nonverbal tests. This again is unlikely, because young participants performed equivalently on both verbal and nonverbal tasks. Thus, the verbal and nonverbal tasks were of equivalent difficulty.

The greater decline in verbal compared to nonverbal IM performance may be a function of the nature of the continuous test. That is, the continuous test was hypothesized to have a significant working memory component, which could have an effect on both TOM and IM. The uniform age-related changes on the discontinuous tests may have occurred because these tests had no working memory component. Support for this proposal, however, is limited, because no age-related decline was observed on the continuous nonverbal IM test, which should also have a working memory component. Nevertheless, the nature of the components of relationships between the articulatory loop and visuospatial scratchpad are still unclear, and researchers are still trying to understand how these working memory components change with increasing age (e.g. Dobbs & Rule, 1989; Salthouse, 1994).

Finally, it is possible that verbal memory declines faster than nonverbal memory. That is, the right-hemisphere hypothesis of aging may have been exactly the opposite of what is actually occurring in the aging brain. It is only recently that researchers are directly comparing age-related changes in memory for verbal and nonverbal information. Surprisingly, Janowski et al. (1996) found that verbal memory (memory for common objects) declines at a greater rate than nonverbal memory (memory for the location of the common objects). They found that when healthy young and older adults' memory for recently learned objects was equated for age (by testing the groups at different retention intervals), memory for the objects' locations was remembered better by the older participants. Likewise, when young and older adults' memory for object location was equated, older adults' memory for the objects was poorer than the younger adults' memory for the same objects. These results are consistent with the notion that age-related decline in memory is asymmetrical, with verbal memory declining faster than nonverbal memory. Janowski et al. (1996) explain their results as due to a possible asymmetric decline in the hippocampus, with the left hippocampus degenerating faster than the right with age. Fabiani and Friedman (1996) found a similar result when they compared age-related changes in TOM and IM for words and common objects on a continuous task. For the words, item memory and list discrimination both declined with age. For the faces, only list discrimination declined with age. Future neurophysiological studies need to compare left vs. right hippocampal decline in normal older individuals. Although the finding of differential verbal memory decline is a new one, it may explain the pattern of performance observed in the continuous tasks.

Hypotheses of Independence of TOM and IM

No double dissociations were observed between TOM and IM. Therefore, none of the experimental tasks supported the hypothesis that TOM and IM are controlled by independent brain systems. On the verbal continuous memory tests, the only significant difference was between IM and TOM performance, with participants performing best on the IM tests. Inspection of means suggested that high frontal participants outperformed low frontal participants on the TOM but not the IM test. However, probably due to small sample size, no significant effect was found. In addition, there were floor effects on the TOM test for participants in the low frontal and low MTL groups. Had performance been off the floor, larger differences between participants may have been observed.

On the nonverbal continuous test, the same pattern of results was observed: all participants performed better on the IM test than the TOM test, but no main effects of frontal or MTL score were found. Again, group differences between performance on the TOM test were greatest when the participants were classified according to frontal lobe score. In addition, the opposite pattern held true for the IM test: group differences on the IM test were greatest when participants were classified according to MTL score. A larger sample size may have found a double dissociation, but none was observed in this experiment. Interestingly, there were no ceiling or floor effects on this task, but the differences between groups was not large.

When working memory demands were minimized, clearer effects of frontal and MTL status were observed. On the discontinuous verbal tests, participants high in frontal ability outperformed those low in frontal ability, regardless of the test type. In addition, participants high in MTL ability performed better than those low in this ability. However, there was no factor score by memory type interaction. These results suggest that both the frontal and medial temporal lobes were involved on the IM and TOM tasks. The extent to which these two brain regions were involved, however, was unclear because floor effects were observed for the low frontal and low MTL groups, perhaps masking a factor score by memory type interaction. The amount of decline between high and low participants could not be assessed due to these floor effects.

Similar results were obtained for the discontinuous nonverbal test. Participants scoring high on the MTL factor outperformed those scoring low on it, regardless of whether IM or TOM was assessed. Although not significant, the mean performance for the participants high on the frontal factor was greater than those low on the factor. This test also would have yielded more explainable results had no floor effects in the low frontal and MTL groups been found.

Another factor important to the understanding of the relationships between TOM and IM concerns the strong correlations between the TOM and IM tests. Temporal order memory has been theorized by some to be a type of source memory: memory for the context in which a fact was learned. Schacter (1987) has proposed that while the medial temporal lobes are responsible for memory of events, the frontal lobes automatically remember the context in which events occurred. Glisky et al. (1995) has found that the MTL and frontal lobe factor double dissociated memory for sentences and memory for the voices that spoke the sentences. Interestingly, the tests of item and voice memory were uncorrelated ($\underline{r}$ = .03). Because such strong correlations were found between IM and TOM in this experiment, it is possible that TOM is somehow works differently than other types of source memory.

If TOM acts differently than other types of memory for context, it is possible that the difficulty in finding a double dissociation between IM and TOM is due to the fact that these two types of memory are not independent. IM and TOM might be hierarchically related. That is, one might need to have correct memory for events before they may be ordered correctly. Thus, the IM would be dependent on the medial temporal lobes, but TOM would require both medial-temporal lobe and frontal lobe processing. For example, the famous patient HM, who was severely impaired when asked to remember events that had occurred since his surgery, had intact TOM only for those items that were correctly remembered (Sagar, Gabrieli, Sullivan, & Corkin, 1984). Similar findings have been replicated in patients with medial temporal and diencephalic amnesia (Shimamura, Janowski, & Squire, 1991). Patients with medial temporal amnesia had intact TOM only for items they remember. In contrast, patients with diencephalic amnesia, who often have damage to fronto-thalamic pathways, had impaired TOM for items they could remember.

The methodology used to compare TOM and IM has often implied the dependence of TOM on IM. For example, Milner's methodology used with patients with frontal and medial temporal lobe lesions such that TOM performance is dependent on whether IM performance was correct. For each test pair, participants first judged if one or both of the items were studied earlier in the list. Then, if they reported that both items were from the list, participants made recency judgements (Milner, 1971; Milner et al., 1991). In fact, most other paradigms, such as list discrimination, have also made TOM dependent on IM performance (e.g. Parkin, Walter & Hunkin, 1995). If it is true that TOM is dependent on IM, then double dissociations should not be obtained. The TOM and IM tests presented in this paper were independent of each other, as test pairs were either IM tests or TOM tests. The lack of double dissociation when the tests were independent lended support to the notion that TOM and IM are dependent upon each other.

Another way to ascertain the relationships of the frontal and medial temporal lobes to TOM and IM could be to partial out the effects of IM and then look for differences in TOM based on frontal lobe functioning. Likewise, the TOM effects could be partialled out before IM performance is examined as a function of medial temporal lobe function.

What does the possibility of a hierarchical relationship between TOM and IM mean for the role of the frontal lobes? It may mean that both the frontal lobes and the temporal lobes are necessary for TOM performance. The temporal lobes may first be involved in memory for the two items, followed by a decision process carried out by the frontal lobes in which relative recency of the two items is assessed. If sample sizes were larger, results from the experiments presented above may have shown that both the frontal factor and MTL factor predicted TOM performance but only the MTL factor predicted IM performance. This pattern of findings was evident (but not significant in the nonverbal discontinuous task (see Table 7). Alternatively, PET findings have implicated the right frontal lobe in the process of strategic retrieval (Tulving, Kapur, Craik, Moscovitch, Houle, 1994, but see also Swick & Knight, 1996). If this theory is valid, frontal and MTL scores may predict performance on both IM and TOM tests. This pattern of results was in fact obtained on the discontinuous verbal TOM and IM tests (See Table 6). If the frontal and medial temporal lobes are both involved in TOM and IM tasks, the critical functions of each of these brain areas could be different for each test. For the TOM test, for example, the frontal lobes may actually process relative time, while for the IM test, they might simply retrieve items in secondary memory. These hypotheses have yet to be tested.

Hypotheses of Laterality of TOM and IM

Many researchers agree that the frontal lobes do not have just one function (e. g., Goldman-Rakic, 1995; Goldman-

Rakic & Friedman, 1991; Petrides, 1995; Shallice & Burgess, 1991). Likewise, the cytoarchitectonic structure of the prefrontal cortex suggests either that the separate areas of the frontal lobes are crucial for several functions, or that they process different kinds of information for a single function (or both). Thus, verbal and nonverbal TOM could be processed by separate brain systems. The tests that made up the frontal factor all have strong verbal components, so it could predict only frontal lobe abilities that have a strong verbal component. If the factor reflected functioning of a discrete area of the frontal lobes, then it may have predicted performance only on one type of TOM task, the tasks that had a strong verbal component. This pattern of performance was observed on the discontinuous tests: the frontal factor predicted performance on the verbal but not nonverbal discontinuous TOM and IM tests. Recent ERP research has documented greater left than right prefrontal activation when making recency judgments, although some bilateral activation was noted (Tendolkar & Rugg, in submission). Other physiological research is would be needed to determine if this effect is reliable and if the nonverbal discontinuous tasks tap right-hemisphere function. Thus, the question of the laterality of TOM as yet, remains unanswered.

The above experiments provided limited support that verbal and nonverbal TOM are processed the left and right frontal lobes, respectively. The frontal factor predicted performance only on both the discontinuous TOM and IM tests. In addition, although significance was not found, on both nonverbal tests, participants in the high frontal group outperformed those in the low frontal group. Thus, the conclusion that the left frontal lobe processes verbal information and the right hemisphere processes nonverbal information could not be supported in this experiment.

Even if the frontal factor had predicted verbal but not nonverbal TOM performance, one could not have concluded that the frontal factor measures left frontal function exclusively. It is possible that verbal and nonverbal TOM were processed in the same hemisphere but in different areas. Direct neurophysiological evidence would have to be obtained in order to clarify the alternatives. Clearly, more research is needed in order to understand the functional relationship between the left and right frontal lobes.

Another way to look for evidence of laterality of TOM is to correlate verbal and nonverbal TOM with neuropsychological measures believed to be most associated with only one hemisphere. The only neuropsychological tests administered to this sample that have been consistently associated with one hemisphere of the frontal lobes are the FAS and Picture Arrangement subtest of the WAIS-RNI. These correlations did not support TOM laterality. For the older participants, FAS was not significantly related to any continuous or discontinuous nonverbal TOM test. Picture Arrangement correlated significantly with verbal TOM rather than nonverbal TOM. Thus, evidence from the administered neuropsychological tests was not supportive of lateralized hemispheric processing of TOM for faces and words.

Role of Primary Memory in TOM and IM Performance

Classifying continuous TOM and IM performance by the number of test items in primary memory yielded some of the most interesting results of this paper. These results suggested that TOM, as measured by the continuous memory paradigm, is dependent on frontal lobe functioning, only when items are in primary memory. The frontal factor but not the medial temporal factor predicted TOM performance when one or more item in a test pair was in primary memory. In addition, all older participants performed better on test items that had at least one item in primary memory. These results suggest, that primary memory is of crucial importance to performance on the continuous memory tasks, regardless of whether the task is to remember items or their order.

The aspect of primary memory that was tapped in this dissociation is unclear. The effect may have been based on holding information in primary memory, manipulating the information that is held in primary memory, or retrieval from primary memory. Because the continuous memory tests required all three of these functions, different methodologies that separate these aspects of primary memory need to be created.

These results raise the possibility that the frontal factor measures those aspects of frontal lobe function that regulate primary memory. Alternatively, the frontal factor also predicted performance on discontinuous TOM, which minimized primary memory. It is possible that the factor measures more than one frontal function, or it is possible that the continuous and discontinuous TOM tests share some sort of function that was picked up by the frontal factor. How to discern the construct that the frontal factor measures is still unclear.

It is possible that the frontal factor predicted performance only when TOM items were in primary memory because the TOM items were retrieved differently than the IM items. On the continuous tests, the same encoding and manipulation processes should have been used for IM and TOM items, because instructions were created such that all items could be tested for item or order. Therefore, it is possible that what differs between the two tasks is the strategy used to retrieve information successfully. This idea is pure speculation, and future studies are needed to understand the relationships between retrieval, primary memory and continuous TOM.

Other possibilities exist to explain the findings with respect to primary memory. First, the pattern of results are in fact only supported by a trend. It is therefore conceivable that it occurred by chance. There was also only a small number of test items in each condition. Only 18 TOM test pairs had at least one item in primary memory and only 24 IM test pairs included an item in primary memory. Also, test items were aggregated such that some items used faces as stimuli while other items used words. Replication is therefore necessary, with a larger number of test pairs in primary memory, and with enough test pairs so that memory for words can be compared to memory for faces.

Second, it is possible that the frontal factor could predict both primary and secondary memory for order. When both items were in secondary memory, TOM performance was at chance levels. Had performance on these test pairs been greater than chance, the frontal factor may or may not have predicted performance on items in secondary memory as well as in primary memory. Counter to this possibility, when both items were in secondary memory, the high frontal group performed at chance while the low frontal group performed greater than chance. This pattern is opposite of what would be expected if the frontal factor predicted TOM performance regardless of whether test items were in primary or secondary memory. Again, replication without floor effects is necessary in order to determine which pattern of performance is reliable.

Role of Strategy, Sequencing and Inhibition in TOM

Older participants. The verbal continuous TOM test correlated strongly with the sequence score of the WAIS-RNI Picture Arrangement subtest. All other correlations were non-significant. When age-related variance was partialed out of the experimental and neuropsychological tests, the correlation became weaker and failed to reach significance. The nonverbal continuous TOM test was uncorrelated with any of the neuropsychological tests. Neither the verbal nor nonverbal discontinuous TOM test correlated with any measures of strategy, sequencing, or inhibition.

Only one conclusion may be drawn from these results. There appeared to be some relationship between sequencing and continuous TOM performance. It was surprising, though, that the verbal TOM test correlated with the nonverbal sequencing test. Sequencing in general could have been the crucial mechanism required to complete the continuous TOM test successfully. Then again, the correlations were not large (in the .3s) once age-associated variance was excluded. It is possible, then, that a larger sample size may have yielded significant effects. Alternatively, an unknown age-related factor may have caused the correlation between sequencing and TOM.

A second, tentative, conclusion can be made by observing the pattern of correlations in the older participants (see Table 10). Evidence did not suggest that TOM in general is dependent on strategy, sequencing and inhibition. Discontinuous TOM test performance was unrelated to the strategy, sequencing, and inhibition tests measured. The pattern contrasting continuous and discontinuous performance was quite clear: continuous tests are somewhat related to the constructs in question while discontinuous tests are not. Since the discontinuous tests clearly measured memory for order, strategy, sequencing and inhibition appear to be related to the <u>way</u> in which TOM is assessed. Measurement of TOM with the continuous method adds variance that is not related specifically to memory for order.

The question then arises: How should TOM be measured? It seems that the way to measure TOM should be the way that it is used most often in everyday situations. Further understanding of the ways that TOM becomes impaired in patients with frontal lobe damage should help in determining the way that TOM should be assessed. That is, if observations suggest that patients with frontal lobe damage have particular difficulty remembering order when they are doing multiple things, the continuous TOM tests may best approximate their everyday situational difficulties. If patients with frontal lobe lesions have difficulty remembering the order of what they did without competing cognitive processes occurring at the same time, then the discontinuous tests may be more appropriate. Even more interestingly, if patients with frontal lobe lesions are impaired on the discontinuous TOM tests, then theories of frontal lobe function must address the notion that inhibition, strategy, and sequencing may not have been necessary. It would be expected that patients with frontal lobe lesions would be impaired due to the age-related decline observed on the discontinuous TOM test reported above. Future testing with patients with frontal lobe damage may help to elucidate what causes the actual deficit on the discontinuous memory tests. In addition, those studying TOM in patients should assess strategic processing and inhibition before looking for specific ordering deficits, as they may explain TOM performance

The constructs of strategy and inhibition have been vaguely defined and measured in this experiment. More specific measures, like those that measured cognitive sequencing, could be correlated with TOM performance. For example, if one theorizes that individuals must use cognitive estimation of temporal distance to perform well on TOM tasks, then a test that measures this more narrowly defined construct would be appropriate. As more specific measures are used, researchers should better understand the mechanisms necessary for TOM.

Using specific tests may also help elucidate brain systems necessary for TOM performance. For example, the University of Pennsylvania Smell Identification Test (UPSIT) has been proposed to measure orbitomedial frontal function (Doty, 1983; Malloy & Richardson, 1994). On the UPSIT, participants identify 40 scratch and sniff items. Although this test is not purported to measure cognitive function, it is known to measure functioning of the olfactory bulbs, which lie just inferior to the orbitomedial prefrontal cortex. Montgomery et al. (1995) have found that UPSIT test predicts the onset of Parkinsonism, although it may have problems detecting frontal lobe function in older adults. Although the UPSIT may not measure cognitive abilities per se, the cognitive abilities associated with orbitomedial prefrontal cortex may decline at similar rates as the olfactory bulbs.

<u>Young participants.</u> As with the older participants, no significant correlations were observed between the

discontinuous TOM tasks and the experimental measures of strategy, sequencing and inhibition, regardless of whether age-associated variance was partialled out or not. Correlations between the neuropsychological tests and the continuous tests were not significant as well.

<u>Recency and Lag Effects</u>

The characteristics of the continuous memory tests were similar to those found in other experiments. For verbal and nonverbal IM and TOM, as retention interval increased, memory performance decreased. That is, memory became poorer as the interval between the most recently studied item and the test pair increased. These results are consistent with the finding that test pairs in secondary memory were remembered more poorly than test pairs with at least one item in primary memory.

Efforts to remove the confound between lag and recency yielded equivocal results. It was hypothesized that TOM performance would increase when the number of items intervening between test pair items was large. This hypothesis was supported with the nonverbal continuous TOM test. In addition, TOM performance was best when lags were long and retention intervals were short. The continuous verbal TOM test did not provide support for the lag hypothesis. Memory performance was not dependent upon lag. These results parallel those in the literature, in which some experiments found an effect of lag (e.g. Milner et al., 1991) and some did not (e.g. Cooper et al., 1993).

An exploratory analysis was conducted for lag on the discontinuous TOM tests. Lag had previously been studied only with the continuous memory paradigm. Thus, conclusions about TOM and lag did not consider the memory system (primary or secondary) from which test items came. A strong main effect for lag was found when the discontinuous TOM test results were aggregated and analysis of memory performance as a function of lag (between 2 and 8) was considered. The findings observed in this experiment support the hypothesis that as lag increases in secondary memory, TOM improves. Future experiments need to be conducted in order to verify this pattern of performance. In addition, because the number of test pairs was so low, aggregated performance had to be considered. Future research should compare the results of verbal and nonverbal TOM in secondary memory, especially since equivocal findings for lag were found with the continuous memory paradigm.

The discontinuous verbal TOM test was more difficult than the discontinuous nonverbal TOM test. Inspection of test pairs revealed that the verbal test had, on average, shorter lags than the nonverbal test. It is possible that the difference in lag between the two tests contributed to the difficulty of the tests. That is, tests with shorter lags should be more difficult than tests with longer lags, because increasing the number of study items between test pair items makes the test pair items more temporally salient. This hypothesis could be addressed in future studies.

Synthesis

The research presented here made several conclusions. First, comparisons between young and older participants supported the hypothesis that TOM declines at a greater rate than IM with age. If TOM indeed relies on frontal lobe functioning, then it supports the hypothesis that the frontal lobes decline with age. Age-related comparisons did not support the theory that the right hemisphere declines faster than the left with age. Second, evidence supported the dependence of TOM on IM, also suggesting that TOM may be as special type of source memory. In addition, it suggested that continuous TOM performance may be related more to primary memory than memory for order. Further, it was consistent with the hypothesis that the continuous memory paradigm possibly measures cognitive sequencing, inhibition, and other strategic processing.

The mechanisms that underlie TOM performance, especially on the discontinuous tests, also remains unclear. An age-related decline was observed for the discontinuous TOM tasks, but primary memory, strategy, sequencing, and inhibition could not explain performance on this task. The question arises: What mediates performance on the discontinuous TOM task? Schacter (1987) proposed that memory for order, like other types of source memory, is acquired automatically. Similarly, Milner (1971) and her colleagues (McAndrews & Milner, 1991; Milner, Petrides & Smith, 1985) has suggested that the frontal lobes automatically parse the ongoing stream of information into discrete temporal units. It is tempting to conclude that the discontinuous tests are measuring this automatic function of the frontal lobes. However, as proposed by Hasher & Zacks (1979), automatic processes are age invariant. Thus, if discontinuous TOM tests were measuring an automatic process, no age-related decline should have been observed. Thus, the mechanism(s) that explains the discontinuous TOM decline are still not clearly understood. Future research could attempt to explain what is responsible for TOM performance.

The cognitive mechanisms addressed in this dissertation are quite general. For example, aside from cognitive sequencing, no other specific strategies were proposed to underlie TOM performance. In addition, exactly what becomes inhibited on these tasks to force a correlation between Stroop and experimental performance is still unclear. Perhaps attention to purely cognitive theories of TOM will help explain these mechanisms in the future.

The ways in which the frontal lobes are involved in memory will likely continue to be a hot topic for researchers. The role of the frontal lobes in TOM as opposed to IM is still poorly understood. As results from aging, electrophysiological and neuropsychological studies are reported, the understanding of the how the frontal lobes contribute to memory in general, and TOM in particular, will undoubtedly increase.

APPENDIX A: CONTINUOUS MEMORY TEST INSTRUCTIONS

On this task, you will see (faces/words) presented on the computer screen. As you see each (face/word) please try to remember what it is as well as the order in which it is presented. From time to time, you will see **two** (faces/words) presented at the same time. For each of these pairs, you will be asked to perform one of two activities.

You may be asked to remember which of the two (faces/words) you studied.

Instead, you may be asked which of the two (faces/words) you studied **FIRST**.

For both types of questions, press the orange button on the left if you think the correct answer is on the left. Press the orange button on the right if you think the correct answer is on the right.

Don't spend too much time on any question.

Please respond as quickly as you can.

You should guess if you are not sure.

Do you have any questions?

[Proceeds with practice]

APPENDIX B: DISCONTINUOUS MEMORY TEST INSTRUCTIONS

Study Phase: On this task, you will see several (faces/words) presented on the computer screen one at a time. For each (face/word), please tell me if your association with it is pleasant or not so pleasant. Say yes if your association with the face is pleasant, and say no if it is not. You should study each (face/word), because later you will be asked (to remember them/the order in which I presented them to you.)

Do you understand?

[Practice]

Are your associations with the (face/word) pleasant or not so pleasant?

Distractor Phase:

Now, please count backwards from 500 until the experimenter tells you to stop.

Do you understand?

Test Phase:

Now you will tested for your memory (of/of the order of) the (faces/words).

You will now see pairs of (faces/words). For each pair, press the button corresponding to the (item you studied/item you studied **FIRST**). Press the orange button on the left if the item you (saw/saw first) was on the left. Press the orange button on the right if the item you (saw/saw first) was on the right. Do you understand?

Please respond as quickly as you can.

Prompt to Next Recency Block:

Now clear you mind of the pictures you have just seen.

Now you will see more (faces/words) and will be asked to do the same thing:

Study the (faces/words) and try to remember their order. As you see each (face/word), tell me if your associations are pleasant or not so pleasant.

Later, you will be tested for your memory of the order of the faces.

Do you have any questions?

REFERENCES

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.

Baddeley, A. D. (1986). Working Memory. Oxford, UK: Clarendon Press.

Baddeley, A. D. (1994). Working Memory: The interface between memory and cognition. In D. L. Schacter & E. Tulving (Eds.), Memory Systems 1994 (pp. 351-368).

Baddeley, A. D., Bressi, S., Della Sala, S., Logie, R., & Spinnler, H. (1991). The decline of working memory in Alzheimer's disease: A longitudinal study. Brain, 114, 2521-2542.

Beatty, W. W. & Monson, N. (1991). Memory for temporal order in multiple sclerosis. Bulletin of the Psychonomic Society, 29, 10-12.

Beck, A. T. (1987). Beck Depression Inventory: Manual. San Antonio, TX: Psychological Corporation.

Bench, C. J., Frith, C. D., Grasby, P. M., Friston, K. J., Pauleau, E., Frackowiak, R. S. J., & Dolan, R. J. (1993). Investigations of the functional anatomy of attention using the stroop test. Neuropsychologia, 31, 907-922.

Benton, A. L. (1968). Differential behavioural effects in frontal lobe disease. Neuropsychologia, 6, 53-60.

Benton, A. L. (1978) The Facial Recognition Test. NY: Oxford University Press.

Benton, A. L. & Hamsher, K. de S. (1976). Multilingual Aphasia Examination [manual]. Iowa City: University of Iowa.

Berman, K. F., Ostrem, J. L., Randolph, C., Gold, J., Goldberg, T. E., Coppola, R., Carson, R. E., Hersovitch, P., & Weinberger, D. R. (1995). Physiological activation of a cortical network during performance of the Wisconsin Card Sorting Test: A positron emission tomography study. Neuropsychologia, 33, 1027-1046.

Bondi, M. W., Kaszniak, A. W., Bayles, K. A., and Vance, K. T. (1993). Contributions of frontal system dysfunction to memory and perceptual abilities in Parkinson's disease. Neuropsychology, 7, 89-102.

Butters, M. A., Kaszniak, A. W., Glisky, E. L., Eslinger, P. J., & Schacter, D. L. (1994). Recency discrimination deficits in frontal lobe patients. Neuropsychology, 8, 343-353.

Coffey, C. E., Wilkinson, W. E., Parashos, I.A., Soady, S. A., Sullivan, R. J., Patterson, L.J., Figiel, G. S., Webb, M. C., Spritzer, C. E., & Djang, W. T. (1992). Quantitative cerebral anatomy of the aging human brain: A cross-sectional study using magnetic resonance imaging. Neurology, 42, 527-536.

Cooper, J. A., Sagar, H. J., Jordan, N., Harvey, N. S., & Sullivan, E. V. (1991). Cognitive impairment in early, untreated Parkinson's disease and its relationship to motor disability. Brain, 114, 2095-2122.

Cooper, J. A., Sagar, H. J., & Sullivan, E. V. (1993). Short-term memory and temporal ordering in early Parkinson's disease: Effects of disease chronicity and medication. Neuropsychologia, 31, 933-949.

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

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

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

Doty, R. L. (1983). The University of Pennsylvania Smell Identification Test Administration Manual. Philadelphia, PA: Sensonics.

Duffy, J. D. & Campbell, J. J. (1994). The regional prefrontal syndromes: A theoretical and clinical overview.

Journal of Neuropsychiatry and Clinical Neurosciences, 6, 379-387.

Farah, M. J., Hammond, K. M., Levine, D. N., & Calvanio, R. (1988). Visual and spatial mental imagery: Dissociable systems of representation. Cognitive Psychology, 20, 439-462.

Folstein, M. F., Folstein, S. F., & 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.

Frith, C. D., Friston, K. J., Liddle, P. F., & Frackowiak, R. S. J. (1991). A PET study of word finding. Neuropsychologia, 29, 1137-1148.

Fuster, J. M. (1985). The prefrontal corrtex, mediator of cross-temporal contingencies. Human Neurobiology, 4, 169-179.

Fuster, J. M. (1991). Role of prefrontal cortex in delay tasks: Evidence from reversible lesion and unit recording in the monkey. In H. S. Levin, H. M. Eisenberg, and A. L. Benton (Eds.), Frontal lobe Function and Dysfunction (pp. 59-71). New York: Oxford University Press.

Fuster, J. M. (1995). Temporal Processing. In J. Grafman, K. J. Holyoak, & F. Boller (Eds.), Annals of the New York Academy of Sciences: Vol. 769. Structure and

Functions of the Human Prefrontal Cortex (pp. 173-182). New York: New York Academy of Sciences.

Fuster, J. M. & Alexander, G. E. (1971). Neuron activity related to short-term memory. Science, 173, 652-654.

Glisky, E. L. (1995). Prospective memory and the frontal lobes. To appear in M. Brandimonte, G. Einstein, & M. McDaniel, eds. Prospective Memory: Theory and Applications. Hillsdale, NJ: Erlbaum.

Glisky, E. L., Polster, M. R., & Routhieaux, B. C. (1995). Double dissociation between item and source memory. Neuropsychology, 9, 229-235.

Goldman, P.S. & Rosvold, H.E. (1970). Localization of function within the dorsolateral prefrontal cortex of the rhesus monkey. Experimental Neurology, 27, 291-304.

Goldman-Rakic, P. S. (1987). Circuitry of the primate prefrontal cortex and regulation of behavior by representational memory. In F. Plum (Ed.), The Nervous System, Higher Functions of the Brain (pp. 373-417). Bethesda, MD: American Psychological Society.

Goldman-Rakic, P. S. (1995). Architecture of the prefrontal cortex and the central executive. In J. Grafman, K. J. Holyoak, & F. Boller (Eds.), Annals of the New York Academy of Sciences: Vol. 769. Structure and Functions of the Human Prefrontal Cortex (pp. 71-84). New York: New York Academy of Sciences.

Goldman-Rakic, P. S. & Friedman, H. R. (1991). The circuitry of working memory revealed by anatomy and metabolic imaging. In H. S. Levin, H. M. Eisenberg, and A. L. Benton (Eds.), Frontal lobe Function and Dysfunction (pp. 72-91). New York: Oxford University Press.

Grafman, J.,Holyoak, K. J., & Boller, F. (Eds.), Annals of the New York Academy of Sciences: Vol. 769. Structure and Functions of the Human Prefrontal Cortex. New York: New York Academy of Sciences.

Hart, R. P., Kwentus, J. A., Wade, J. B., & Taylor, J. R. (1988). Modified Wisconsin Sorting Test in elderly normal, depressed and demented patients. The Clinical Neuropsychologist, 2, 49-56.

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processing memory. Journal of Experimental Psychology, General, 108, 356-388.

Haug, H., Barmwater, U., Eggers, R., Fischer, D., Kuhl, S., & Sass, N. L. (1983). Anatomical changes in the aging brain: Morphometric analysis of the human prosencephalon. in J. Cervos-Navarro & H. I. Sarkander (Eds.), Aging: Vol. 21. Brain Aging: Neuropathology and Neuropharmacology (pp. 1-12). New York: Raven Press.

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

Hertzog, C., & Schaie, K. W. (1988). Stability and change in adult intelligence: 2. Simultaneous analysis of longitudinal means and covariance structures. Psychology and Aging, 3, 122-130.

Horel, J. A. (1994). Some comments on the special cognitive functions claimed for the hippocampus. Cortex, 30, 269-280.

Janowski, J. S., Carper, R. A., & Kaye, J. A. (1996). Asymmetrical memory decline in normal aging and dementia. Neuropsychologia, 34, 527-535.

Janowski, J. S., Shimamura, A. P., Kritchevski, M. & Squire, L. R. (1989). Cognitive impairment following frontal lobe damage and its relevance to human amnesia. Behavioral Neuroscience, 103, 548-560.

Janowsky, J. S., Shimamura, A. P. & Squire, L. R. (1989). Source memory impairment in patients with frontal lobe lesions. Neuropsychologia, 27, 1043-1056.

Kaplan, E., Fein, K., Morris, R., & Delis, D. (1991) WAIS-R as a Neuropsychological Instrument. San Antonio, Tx: The Psychological Corporation.

Kausler, D. H., Lichty, W., & Davis, R. T. (1985). Temporal memory for performed activities: Intentionality and adult age differences. Developmental Psychology, 21, 1132-1138.

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

Kesner, R. P., (1993). Paired associate learning in the rat: Role of hippocampus, medial prefrontal cortex, and parietal cortex. Psychobiology, 21, 183-192.

Kesner, R. P. & Holbrook, T. (1987). Dissociation of item and order spatial memory in rats following medial prefrontal cortex lesions. Neuropsychologia, 25, 653-664.

Kimberg, D. Y. & Farah, M. J. (1993). A unified account of cognitive impairments following frontal lobe damage: The role of working memory in complex, organized behavior. Journal of Experimental Psychology, General, 122, 411-428.

Klisz, D. (1978). Neuropsychology and medical disorders. In M. Storandt, I. C. Seigler, & M. F. Elias (Eds.), The Clinical Psychology of Aging (pp. 71-95). New York: Plenum Press.

Knight, R. T., Scabini, D. & Woods, D. L. (1989). Prefrontal aging of auditory transmission in humans. Brain Research, 504, 338-342.

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

Kuhl, D. E., Metter, E. J., Riege, W., H., & Hawkins, R. A. (1984). The effect of normal aging on patterns of local cerebral glucose utilization. Annals of Neurology, 15, S133-137.

Kuhl, D. E., Metter, E. J., Riege, W., H., & Phelps, M. E. (1982). Effects of human aging on patterns of local cerebral glucose utilization determined by the F-18 Fluoro-deoxyglucose method. Journal of Cerebral Blood Flow and Metabolism, 3, s494-s495.

LaRue, A. (1992). Aging and Neuropsychological Assessment (pp. 47-78). New York: Plenum Press.

Levin, H. S., Eisenberg, H. M., & Benton, A. L., Eds. (1991). Frontal lobe Function and Dysfunction. New York: Oxford University Press.

Libon, D. J., Glosser, G., Malamut, B. L., Kaplan, E., Goldberg, E., Swenson, R., & Sands, L. P. (1994). Age, executive functions, and visuospatial functioning in healthy older adults. Neuropsychology, 8, 38-43.

Malloy, P. M. & Duffy, J. D. (1992). The frontal lobes in neuropsychiatric disorders. In F. Boller & H. Spinnler (Eds.), Handbook of Neuropsychology, Vol. 8, (pp. 203-232). New York: Elsevier.

Malloy, P. F. & Richardson, E. D. (1994). Assessment of frontal lobe functions. Journal of Neuropsychiatry and Clinical Neurosciences, 6, 339-410.

Martin, R. C., Loring, D. W., Meador, K. J., & Lee, G. P. (1990). The effects of lateralized temporal lobe dysfunction on formal and semantic word fluency. Neuropsychologia, 28, 823-829.

McAndrews, M. P. & Milner, B. (1991). The frontal cortex and memory for temporal order. Neuropsychologia, 29, 849-859.

McCormack, P. D. (1981). Temporal coding by young and elderly adults: A test of the Hasher-Zacks model. Developmental Psychology, 17, 509-515.

McCormack, P. D. (1982). Temporal coding and study-phase retrieval in young and elderly adults. Bulletin of the Psychonomic Society, 20, 242-244.

McCormack, P. D. (1984). Temporal coding by young and elderly adults in a list-discrimination setting. Bulletin of the Psychonomic Society, 22, 401-402.

McFie, J. & Thompson, J. A. (1972). Picture arrangement: A measure of frontal lobe function? British Journal of Psychiatry, 121, 547-552.

Milner, B. (1964). Some effects of frontal lobectomy in man. In J. M. Warren & K. Akert (Eds.), The Frontal Granular Cortex and Behavior (pp. 313-334). New York: McGraw-Hill.

Milner, B. (1971). Interhemispheric differences in the localization of psychological processes in man. British Medical Bulletin, 27, 272-277.

Milner, B., Corsi, P. & Leonard, G. (1991). Frontal lobe contribution to recency judgements. Neuropsychologia, 29, 601-618.

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

Montgomery, E. B., Jr., Koller, W. C., Newman, M. C., LaMantia, T. J. K., Swanson-Hyland, E. F, & Kaszniak, A. W. (1995). Objective test to confirm Parkinson's disease. Paper to be presented at the 23rd Annual Meeting of the International Neuropsychological Society, Seattle, WA.

Moscovitch, M. (1994). Memory and working with memory: Evaluation of a component process model and comparisons with other models. In Schacter, D. L. & Tulving, E. (Eds.), Memory Systems 1994. Cambridge, MA: MIT Press.

Moscovitch, M. & Winocur, G. (1995). Frontal lobes, memory, and aging. In J. Grafman, K. J. Holyoak, & F. Boller (Eds.), Annals of the New York Academy of Sciences: Vol. 769. Structure and Functions of the Human Prefrontal Cortex, Annals of the New York Academy of Sciences (pp. 119-150). New York: The New York Academy of Sciences.

Naveh-Benjamin, M. (1990). Coding of temporal order information: An automatic Process? Journal of Experimental Psychology: Learning, Memory, and Cognition, 16, 117-126.

Parkin, A. J., Walter, B. M., & Hunkin, N. M. (1995). Relationships between normal aging, frontal lobe funciton, and memory for temporal order. Neuropsychology, 9, 304-312.

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

Passingham, R. (1993). The Frontal lobes and Voluntary Action, Oxford Psychology Series, No. 21. New York: The Clarendon Press.

Perlmutter, M., Metzger, R., Nezworski, T., & Miller, K. (1981). Spatial and temporal memory in 20 and 60 year olds. Journal of Gerontology, 36, 59-65.

Petrides, M. (1994). Frontal lobes and working memory: Evidence from investigations of the effects of cortical excisions in nonhuman primates. In F. Boller & J. Grafman (Eds.), Handbook of Neuropsychology, Vol. 9 (pp. 59-82). Amsterdam: Elsevier.

Petrides, M. (1995). Functional organization of the human frontal cortex for mnemonic processing: Evidence from neuroimaging studies. In J. Grafman, K. J. Holyoak, & F. Boller (Eds.), Annals of the New York Academy of Sciences: Vol. 769. Structure and Functions of the Human Prefrontal Cortex, Annals of the New York Academy of Sciences (pp. 85-96). New York: The New York Academy of Sciences.

Plude, D. J., Milberg, W. P. & Cerella, J. (1986). Age differences in depicting and perceiving tridimensionality in simple line drawings. Experimental Aging Research, 12, 221-225.

Quintana, J. & Fuster, J. M. (1992). Mnemonic and predictive functions of cortical neurons in a memory task. NeuroReport, 3, 721-724.

Raven, J. C. (1960). Guide to the Standard Progressive Matrices. London: H. K. Lewis.

Reitan, R. M., & Davison, L. A. (1974). Clinical Neuropsychology: Current Status and Applications. New York: Halstead Press.

Richer, F., Decary, A., Lapierre, M. F., Rouleau, I., Boubier, G., Saint-Hilaire, J. M. (1993). Target detection deficits in frontal lobectomy. Brain and Cognition, 21, 203-211.

Robinson, A. L., Heaton, R. K., Lehman, R. A. W., & Stilson, D. W. (1990). The utility of the Wisconsin Card Sorting Test in detecting and localizing frontal lobe lesions. Journal of Consulting and Clinical Psychology, 48, 605-614.

Sagar, H. J., Cohen, N. J., Sullivan, E. V., Corkin, S., & Growdon, J. H. (1988). Remote memory function in Alzheimer's disease and Parkinson's disease. Brain, 111, 185-206.

Sagar, H. J., Gabrieli, J. D. E., Sullivan, E. V., & Corkin, S. (1984). Temporal contextual memory in amnesia. Society for Neuroscience Abstracts, 10, 384.

Sagar, H. J., Sullivan, E. V., Gabrieli, J. D. E., Corkin, S., & Growden, J. H. (1988). Temporal ordering and short-term memory deficits in Parkinson's disease. Brain, 111, 525-539.

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

Schacter, D. L. (1987). Memory, amnesia, and frontal lobe dysfunction. Psychobiology, 15, 21-36.

Schacter, D. L., Kaszniak, A. W., & Kihlstrom, J. F. (1991). Models of memory and the understanding of memory disorders. In T. Yanagihara & R. C. Petersen (Eds.), Memory Disorders: Research & Clinical Practice, New York: Marcel Dekker.

Schaie, K. W., & Schaie, J. P. (1977). Clinical assessment and aging. In J. E. Birren & K. W. Schaie (Eds.), Handbook of the Psychology of Aging (pp. 692-723). New York: Van Nostrand Reinhold.

Shallice, T. & Burgess, P. (1991) Higher-order cognitive impairments and frontal lobe lesions in man. In Levin, H. S., Eisenberg, H. M., & Benton, A. L., (Eds.), Frontal lobe Function and Dysfunction (pp. 125-138). New York: Oxford University Press.

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

Shimamura, A. P. (1995). Memory and the prefrontal cortex. In J. Grafman, K. J. Holyoak, & F. Boller (Eds.), Annals of the New York Academy of Sciences: Vol. 769. Structure and Functions of the Human Prefrontal Cortex (pp. 151-159). New York: The New York Academy of Sciences.

Shimamura, A. P., Janowsky, J. S. & Squire, L. R. (1990). Memory for the temporal order of events in patients with frontal lobe lesions and amnesic patients. Neuropsychologia, 28, 803-813.

Shimamura, A. P., Janowsky, J. S. & Squire, L. R. (1991). What is the role of frontal lobe damage in memory disorders? In Levin, H. S., Eisenberg, H. M., & Benton, A. L., (Eds.), Frontal lobe Function and Dysfunction (pp. 173-198). New York: Oxford University Press.

Smith, M. L. & Milner, B. (1988). Estimation of frequency of occurrence of abstract designs after frontal or temporal lobectomy. Neuropsychologia, 26, 297-306.

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

Squire, L. R. (1994). Declarative and nondeclarative memory: Multiple brain systems supporting learning and memory. In Schacter, D. L. & Tulving, E. (eds.), Memory Systems 1994. Cambridge, MA: MIT Press.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. Journal of Experimental Psychology, 18, 643-662.

Stuss, D. T. (1991). Interference effects on memory function in postleukotomy patients: An attentional perspective. In Levin, H. S., Eisenberg, H. M., & Benton, A. L., (eds.), Frontal lobe Function and Dysfunction. New York: Oxford University Press.

Sullivan, E. V. & Sagar, H. J. (1989). Nonverbal recognition and recency discrimination in Parkinson's disease and Alzheimer's disease. Brain, 112, 1503-1517.

Sullivan, E. V., Sagar, H. J., Gabrieli, J. D. E., Corkin, S., & Growdon, J. H. (1989). Different cognitive profiles on standard behavioral tests in Parkinson's disease and Alzheimer's disease. Journal of Clinical and Experimental Neuropsychology, 11, 799-820.

Swartz, B. E., Halgren, E., Fuster, J., & Mandelkern, M. (1994). An ^{18}FDG-PET study of cortical activation during a short-term visual memory task in humans. NeuroReport, 5, 925-928.

Swick, D. & Knight, R. T. (1996). IS prefrontal cortex involved in cued recall? A neuropsychological test of PET findings. Neuropsychologia, 34, 1019-1028.

Taylor, A. E., Saint-Cyr, J. A., & Lang, A. E. (1986). Frontal lobe dysfunction in Parkinson's disease. The cortical focus of neostriatal outflow. Brain, 109, 845-883.

Tendolkar, I. & Rugg, M. D. (1996). Brain potentials dissociate recency and recognition memory. Manuscript submitted for publication.

Thurstone, L. L., & Thurstone, T. G. (1949). Examiners manual: SRA Primary Mental Abilities Test (Form 11-17). Chicago: Science Research Associates.

Trenerry, M. R., Crosson, B., DeBoe, J., & Leber, W. R. (1989). The Stroop Neuropsychological Screening Test. Odessa, FL: Psychological Assessment Resources Corp.

Tulving, E. & Colotla, V. A. (1970). Free recall of trilingual lists. Cognitive Psychology, 1, 86-98,

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

Vakil, E., Blachstein, H., & Hoofien, D. (1991). Automatic temporal order judgement: The effect of intentionality of retrieval on closed-head-injured patients.

Journal of Clinical and Experimental Neuropsychology, 13, 291-298.

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

Vendrell, P., Junque, C., Pujol, J., Jurado, M. A., Molet, J., & Grafman, J. (1995). The role of prefrontal regions in the Stroop task. Neuropsychologia, 33, 341-352.

Vilkki, J. & Holst, P. (1989). Deficient programming in spatial learning after frontal lobe damage. Neuropsychologia, 27, 971-976.

Vriezen, E. R. & Moscovitch, M. (1990). Memory for temporal order and conditional associative-learning in patients with Parkinson's disease. Neuropsychologia, 28, 1283-1293.

Walsh, K. W. (1987). Neuropsychology (2nd ed.). Edinburgh: Churchill-Livingstone.

Warrington, E. K., & Shallice, T. (1969). The selective impairment of auditory-verbal short-term memory. Brain, 92, 885-896.

Wechsler, D. (1958). The Measurement and Appraisal of Adult Intelligence (4th ed.). Baltimore: Williams & Wilkins.

Wechsler, D. (1981). Wechsler Adult Intelligence Scale--Revised [manual]. New York: Psychological Corporation.

Wechsler, D. (1987). Wechsler Memory Scale--Revised [manual]. New York: Psychological Corporation.

Wilson, J. R., DeFries, J. C., McClearn, G. E., Vandenberg, S. G., Johnson, R. C., & Rashad, M. N. (1975). Cognitive abilities: Use of family data as a control to assess sex and age differences in two ethnic groups. International Journal of Aging and Human Development, 6, 161-176.

Winocur, G. (1992). A comparison of normal old rats and young adult rats with lesions to the hippocampus or prefrontal cortex on a test of matching-to-sample. Neuropsychologia, 30, 769-781.

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