Age-related changes in the neural and cognitive processes relating to memory retrieval under conditions of full and divided attention.

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

We examined the neural and cognitive processes engaged during auditory verbal recognition performance under full attention (FA) and divided attention (DA) conditions in younger and older adults. Recognition was disrupted by a word (DA-word), but not digit-based (DA-digit) distracting task, performed concurrently with retrieval. In Study 1, a multivariate functional magnetic resonance imaging analysis technique, Partial Least Squares (PLS) was used to identify distributed patterns of brain activity most related to the different conditions and behaviours. We found that similar retrieval networks were recruited during the FA and DA-digit, but not DA-word, condition in both age groups, mirroring behavioural performance. There was, however, an age-related change in the brain regions that predicted successful memory performance. In addition, we found that a neural network relating to hippocampal activity predicted memory success during the FA and DA-digit, but not DA-word, condition in younger, but not older, adults. In study 2, we used a Remember-Know paradigm to examine how manipulations of DA affect recollective and familiarity-based retrieval processes. Younger and older adults showed an increase in false Remember responses during both DA conditions and decreased accuracy in Know responses only during the word-based DA condition. In addition, aging was associated with decreased accuracy in Remember, but not Know, responses, in both DA conditions. In a follow-up experiment, we showed that these results cannot be accounted for by differences in difficulty level of the chosen distracting tasks. Results suggest that recollective processes rely on attentional resources during retrieval. Together these studies show that declines in available attentional resources, common with advancing age, affect both the neural networks used during retrieval, and the qualitative nature of the memories that are retrieved. Results also suggest that familiarity processes rely on the reactivation of content-specific representations, mediated by a neural network relating to hippocampal activity in younger, but not older, adults.

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Table of Contents

List of Tables

List of Figures

Study 2, Experiment 2. Mean recognition accuracy under full and divided attention conditions in Younger Adults.

Chapter 1
General Introduction

The ability to remember our past experiences requires an assembly of cognitive processes which are influenced by our current expectations, goals, and surrounding environment (Schacter, 1996). These variables often alter the relative ease with which memory retrieval occurs. For example, we are frequently unable to recall an event despite our best efforts, only to have that memory ‘pop’ into our head at some later time. In addition, older adults often complain that the ability to willingly retrieve information from memory becomes more difficult with age. These observations suggest that the ability to access our memories changes, depending on the particular situation, and is affected by the passage of time (or by advancing age). This Masters thesis explores how memory retrieval is affected when distracting stimuli compete for our mental resources, and how the normal aging process interacts with these effects.

The general introduction to this thesis is broken into three sections. It begins with a brief review of the study of memory, followed by a summary of the current knowledge of how memory processes are affected by cognitive aging. The last section describes the divided attention technique, and reviews past research that has used this technique to identify the resource requirements of the processes involved in episodic memory.

1.1 A Brief Introduction to Memory

Human memory has evolved to retain multiple types of information, so that the knowledge gained from our past experiences may be applied to a range of situations. This has led some cognitive psychologists to propose that there are multiple memory systems, each designed to manage the retention and use of different forms of memory (Squire, 1993). Most psychologists initially divide human memory into short-term and long-term memory stores (Broadbent, 1958; James, 1890). The short-term store is designed to process the temporary storage and manipulation of information, and is both limited in the capacity and time span on which it operates. In contrast, long term memory is designed for the long-term and unlimited storage, management, and retrieval of information (Miller, 1956).

The long term store has been further divided into non-declarative and declarative memory stores (Tulving, 1972). Non-declarative memory can be thought of as the unconscious ability to express learned information, such as the ability to ride a bike. Alternatively, declarative memory requires the conscious recollection of facts and events. These declarative memories are further classified into semantic or episodic memories (Tulving, 1983). Semantic memories involve information of factual events and general knowledge, such as the knowledge that the sun is a star, whereas episodic memories include the events and situations that you have personally experienced, such as the memory of your first kiss.

Much of the research supporting the multiple memory systems view comes from research with brain-damaged patients. These studies find that lesions in different regions of the brain selectively disrupt different forms of memory. For example, individuals with medial temporal lobe damage are unable to form new episodic memories, although they are able to form new non-declarative memories (Scoville & Milner, 1966). In contrast, damage to other brain regions, such as the frontal lobe or amygdala, have been found to impair short-term and non-declarative memory functions respectively, while leaving episodic memory functions intact (Bechara et al. 1995; Shallice & Warrington, 1970). These findings show that different memory stores rely on unique neural processes, indicating that they are functionally distinct.

Aging is associated with a variety of cognitive and neural changes. The next section considers how normal aging affects the cognitive processes involved in these multiple memory stores, as well as what these changes can tell us about the nature of human memory.

1.2 Cognitive Aging and Memory

Older adults often complain that their memory abilities weaken with age, but research shows that not all memory processes are equally disrupted by advancing age. Older adults have relatively preserved performance on tests of non-declarative (Light & Singh, 1987) and semantic (Park, Polk, Mikels, Taylor, & Marshuetz, 2001;

Salthouse, 1982, 1991) memory, such as tests of repetition priming (Fleischman, Wilson, Gabrieli, Bienias, & Bennett, 2004), vocabulary level (Park et al., 2001; Salthouse, 1991) or general word knowledge (Salthouse, 1982). Conversely, performance on short-term memory and episodic memory tasks show a marked decline with age (Park et al., 2001). These age-related impairments, however, appear to depend on the executive control or attentional demands of the task. For example, older adults show better performance on short-term memory tasks that require the simple maintenance of information (for example, repeating stimuli in the order they were presented), as compared to those that involve the manipulation of information (for example, repeating stimuli in the reverse order of presentation); (Bopp & Verhaeghen, 2005). In addition, episodic memory tests that provide a retrieval cue, such as recognition or cued-recall tests, show smaller age-related deficits than those tests that require the participant to reconstruct the episode in which the information was first experienced, such as free recall or source memory tests (Craik, 1986; Craik & McIntryre, 1987).

Multiple theories have been proposed to explain the memory deficits observed with age. These deficits have been framed in terms of a general slowing in processing speed (Salthouse, 1996), less effective cognitive inhibition processes (Hasher & Zacks, 1988), or reduced attentional resources (Craik, 1986), among others. Although no one single framework has been able to adequately describe all of the data on memory and aging, most theories converge on the idea that changes in brain function, particularly in the frontal lobe, underlie these deficits (Baddeley & Wilson, 1988; Craik, 1983; Craik & Byrd, 1982; Fuster, 1997; Knight, Grabowecky, & Scabini 1995; Luria, 1966; Rabinowitz, Craik & Ackerman, 1982; Shallice & Burgess, 1991).

Normal aging is associated with an expansion of the cerebral ventricles, as well as shrinkage of grey and white matter in the brain (Raz, 2005). However, regional analyses show that not all brain areas are equally affected by age. The frontal lobes appear to be the most greatly affected, showing sharp declines in both volume (Raz, 2005) and cerebral metabolism (Lee et al., 2005). Conversely, the occipital and temporal lobes show modest age-related deterioration. In addition, the medial temporal structures involved in declarative memory functions, such as the hippocampus and entorhinal cortex, show nonlinear trajectories of volume loss, indicating they may only show pathology in the very latest years of life (Raz, 2005). These findings supplement the behavioural results, in that those memory tasks involving executive or attentional control processes, which are believed to rely on frontal lobe structures, are most impaired by age.

Research to date supports a reduced resource view of cognitive aging (Craik, 1983, 1986; Craik & Byrd, 1982), which is a framework that is referenced throughout this thesis. The resource view assumes that a limited supply of cognitive resources is available to perform a cognitive task (Kahneman, 1973), and that neural changes in the frontal lobe of the aging brain lead to a decline in the amount of available resources (Craik, 1983). Older adults thus require more resources to carry out a given cognitive task than younger adults. If the memory task requires significant resource requirements, such as those that require high levels of executive and attentional control functions, this loss in resources with age then begins to affect behavioural performance. At the neural level, cognitive resources may be described as 'neural units' or in the case of functional Magnetic Resonance Imaging (fMRI), as frontal lobe activity (Reuter-Lorenz et al., 1999). Since older adults require greater cognitive resources to perform a task, older adults should engage more neural units to perform a given cognitive task than younger adults. This pattern has been found using fMRI within and outside of the memory domain, with older adults showing additional neural activity in the frontal lobes compared to younger adults during episodic memory retrieval (Cabeza et al., 1997), episodic memory encoding (Stebbins et al., 2002), working memory (Reuter-Lorenz et al., 2000), perception (Grady et al., 1994), and inhibitory control (Nielson, Langernecker, & Garavan, 2002), tasks (for a review see Cabeza, 2002).

Early work proposing a resource view of aging expressed cognitive resources in terms of the amount of attention a person could devote to a given task (Craik & Byrd, 1982; Craik, Byrd, & Swanson, 1987). Such a description illustrates that there is a fundamental link between cognitive resources, executive control, and attention. For example, performance on tasks requiring executive control are significantly impaired when attention is reduced in younger adults (Varhaeghen & Cerella, 2002), and often mimics that of older adults performing the same task under full attention conditions (Craik & Byrd, 1982; Craik, Byrd, & Swanson, 1987).

Consequently, any manipulation used to reduce the amount of attention (or attentional resources) one can devote to a cognitive task is assumed to reduce the amount of cognitive resources available for that task. This assumption has been used extensively to measure the unique resource demands of cognitive processes by examining how behavioural performance in younger and older adults is affected by manipulations of attention. In the next section we examine how one such method, the divided attention technique, has been used to determine the resource requirements of various cognitive processes, including those involved in memory.

1.3 Memory Processes and the Divided Attention Technique

The divided attention technique has been widely used to measure the resources required to perform a cognitive task, and can provide insight into how these might differ in younger compared to older adults. The technique assumes that people should be able to perform two tasks simultaneously as long as the resource requirements of the two tasks do not overlap (Brooks, 1968). For example, an individual can easily walk and chew gum at the same time, but trying to suck on a mint and chew gum simultaneously is much more difficult, since both tasks require the same body part (Neath & Suprenant, 2003). Using this logic, the method requires participants to perform a primary task of interest either alone (the full attention, or FA, condition) or while performing a concurrent task (the divided attention, or DA, condition). A measure of interference is then determined by calculating how much primary task performance declines from the FA to DA condition. The magnitude of this interference is believed to represent the degree to which the two tasks use similar cognitive resources.

The DA technique can be used to infer the resource demands of memory encoding, separately from memory retrieval. This can be achieved by asking participants to engage in a concurrent, distracting task, during either encoding, or retrieval. Past works shows that when attention is divided at encoding, or when participants are learning new information, there are large detriments in memory performance (Baddley, Lewis, Eldridge, & Thompson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Mordock, 1965; Naveh-Benjamin, Craik, Guez, & Dori, 1998). This finding corresponds to our intuition, in that it suggests that the more attention given to a memory task, the better memory for those items will be. However, when attention is divided at retrieval, or when participants are asked to remember previously learned material, either no decrement or only a small decrement in memory performance is observed (Baddley, Lewis, Eldridge, & Thompson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Mordock, 1965; Naveh-Benjamin, Craik, Guez, & Dori, 1998). This finding is surprising, as memory retrieval is often experienced, and described, as an effortful process. (Just think of the last time you tried to remember the answer to an exam question! You definitely felt how resource demanding the process could be!)

The finding that DA does not affect encoding and retrieval processes equally has significant implications for memory research, because it contradicts most classical theories of memory that suggest memory encoding and retrieval require similar cognitive processes. For example, theories of transfer appropriate processing (Tulving, 1983), repetition of operations (Koler, 1973), and encoding specificity (Roediger, Weldon, & Challis, 1989), all propose that there is extensive overlap in the type of cognitive processes engaged during encoding and retrieval. That is, we remember information by re-creating the encoding environment. If encoding and retrieval are indeed linked, they should be similarly affected by experimental manipulations. However, the above findings suggest that encoding and retrieval are quite different processes, in that encoding requires a greater amount of attentional resources than retrieval.

However, researchers have also examined secondary task costs (i.e., the degree to which performance on the distracting task suffers when performed with the memory task, as compared to FA, conditions) as another method of examining the amount of attention or effort required to perform a memory task. The rationale is that the greater the amount of attentional resources required for a memory task to proceed, the greater the decrement in distracter task performance, from FA to DA conditions, will be. Research shows that although DA at retrieval produces little deficit in memory performance, there are deficits in performance of the distracting task under these DA conditions, and that the distracting task deficits are greater at retrieval, than those found when attention is divided at encoding (Anderson et al., 1998; Craik & McDowd, 1987; Craik, Naveh-Benjamin, & Anderson, 1996). This suggests that although DA at retrieval proceeds in a relatively obligatorily manner (i.e., memory performance is relatively unaffected when attention is divided at retrieval) retrieval does require some attentional resources to proceed (as indicated by the detriment in distracter task performance), (Craik, Naveh-Benjamin, & Anderson, 1996).

Given that the normal aging process is believed to be related to a loss in attentional resources, one might also learn about the attentional resource demands of a given cognitive process through work with older adults. Since older adults are believed to have a more limited supply of attentional resources, one might expect that they would be particularly vulnerable to effects of distraction, which draws further on these limited resources. Research has shown that older adults are more disadvantaged than young when a working memory task is performed concurrently with a secondary task (Salthouse, Rogan, & Prill, 1984; McDowd & Craik, 1988), though this finding is not always replicated, and may be related to complexity of the working memory task. With respect to long-term memory, several studies have shown that when a distracting task is performed during the encoding phase, the reduction in memory performance is equivalent in younger and older adults (Anderson, Craik & Naveh-Benjamin, 1998; Nyberg, Nilsson, Olofsson & Bäckman, 1997) although other studies have found that older adults are more susceptible than young adults to interference from DA at encoding (Puglisi, Park, Smith & Dudley, 1988; Park, Smith, Dudley & Lafronza, 1989).

In contrast to encoding, most studies have found that older adults are no more susceptible to memory interference than are young adults when attention is divided during the retrieval stage (Anderson et al., 1998; Fernandes & Moscovitch, 2003; Fernandes et al., 2004; Macht & Buschke, 1983; Nyberg, Nilsson, Olofsson, & Bäckman, 1997; Park et al., 1989; Whiting & Smith, 1997). However, research also shows that when attention is divided at retrieval, the costs in distracter task performance are greater in older than in younger adults (Anderson et al., 1998; Craik & McDowd, 1987; Whiting & Smith, 1997). This finding has led some (Anderson et al., 1998) to conclude that older adults have a reduction in resources available to engage in demanding mnemonic operations (e.g., maintaining set, using strategies) during retrieval, as indexed by higher distracting task costs, but that the actual retrieval of information is relatively preserved.

These studies suggest that general attentional resources play a more indirect role during retrieval than at encoding: division of attention during encoding disrupts subsequent memory, but recovery of memory traces is less affected by manipulations of attention during retrieval. These findings also suggest that although memory retrieval may occur obligatorily (i.e., it is not disrupted by a distracting task), it requires attentional resources, as indexed by the higher costs to distracter task performance from DA at retrieval than DA at encoding. Finally, the resource requirements for retrieval are greater for older adults, as indexed by their larger overall distracting task costs.

Although most studies have found that retrieval is resilient to manipulations of attention during retrieval, there is work that shows that DA at retrieval can lead to large disruptions in memory performance. Fernandes and Moscovitch (2000, 2002) found that retrieval of words is significantly disrupted when participants concurrently perform a word-based distracting task during retrieval, as compared to a digit- or picture-based task. A decrement in verbal memory of about 30% from FA levels was observed when the concurrent task was word-based, whereas an equally demanding digit-based task produced a decrement of only 10 to 15%. Since memory retrieval was disrupted maximally when the distracting task employed words (material-specific manipulations of attention), and not digits or pictures (general manipulations of attention), the authors suggested that memory interference during retrieval arises from competition for content-specific representations, that are common to both the verbal memory and word-based distracting task. Furthermore, older adults were shown to have an equal amount of memory disruption as younger adults when they were required to perform a word-based distracter task during verbal retrieval, suggesting that these content representations are intact in older adults (Fernandes & Moscovitch, 2003; Fernandes, Davidson, Glisky, & Moscovitch, 2004).

These findings are in line with the component-process model first proposed by Moscovitch and Umiltà (1990, 1991). According to the model, episodic retrieval requires at least two main components, one resource-demanding and the other less so. The first is mediated by the prefrontal cortex (PFC), and represents resource-demanding processes that are needed to maintain and implement strategic aspects of retrieval, such as retrieval mode, search and monitoring, and the coordination of competing task demands. The second component of the model, believed to be mediated by the medial temporal lobes/hippocampus (MTL/H), involves the relatively automatic re-activation of memory traces resulting from their interaction with memory cues, a process termed ecphory by Semon (1924; see also Schacter, Eich, & Tulving, 1978). The memory trace itself is presumed to consist of an ensemble of MTL/H and neocortical neurons, the latter mediating the representations of the memory event itself, with the MTL/H acting as a pointer or index to the neocortical representations to which it is bound. At retrieval, the cue is presumed to activate the MTL/H index, which in turn reactivates the cortical representations leading to recovery of the memory trace.

According to Fernandes & Moscovitch (2000), because this ecphoric process is presumed to require little, if any, resources (Moscovitch, 1994), it is not affected by DA manipulations at retrieval. However, when distracter task material is similar to that being retrieved from memory, DA at retrieval is presumed to exert its effect, not by competing for general resources, but by competing for neocortical representations that the distracting task and memory trace (or the ecphoric recall process) have in common (Fernandes & Moscovitch, 2000, 2003). The model can also explain why older adults, believed to have a reduction in available attentional resources, are not more affected than young by the word-based DA condition during retrieval (Anderson et al., 1998; Fernandes & Moscovitch, 2003; Macht & Buschke, 1983; Nyberg et al., 1997; Whiting & Smith, 1997). That is, the locus of memory interference at retrieval, according to the model, occurs at the level of reactivation of perceptual representations (content of the memory trace), which are presumably intact in older adults, and not at the level of competition for attentional resources, which are lacking in older adults.

In summary, although memory retrieval can proceed obligatorily under some DA conditions (cf Anderson et al., 1998; Craik et al., 1996; Naveh-Benjamin et al., 2000), retrieval requires access to the content of the memory trace. If a particular combination of concurrent tasks creates competition for content representations, or hampers re-activation of such representations by the MTL/H, then retrieval will be disrupted.

1.4 Goals of the Current Thesis

The aim of the current thesis is twofold. First we wish to characterize the neural basis of memory interference produced by general compared to material-specific DA conditions during retrieval. The second is to examine how these DA conditions affect the qualitative nature of memories that are retrieved.

The first study of this thesis uses a multivariate functional magnetic resonance imaging (fMRI) technique to examine how neural networks, or patterns of brain activation, are affected by manipulations of attention. Although previous work has considered how DA at retrieval affects the neural processes recruited during general manipulations of attention, no study has examined how material-specific manipulations affect the networks used to guide memory retrieval, as well as how these effects interact with age. Such an analysis will help identify the unique processing demands of retrieval, under different attentional conditions, what neural networks are recruited during these processes, and how these processing demands and their associated networks change with age. This section begins with a general explanation about what multivariate analyses can tell us about the neural processes relating to cognition, followed by the specific application of this technique to the study of memory, divided attention, and aging.

The second study of this thesis then explores whether general and material-specific manipulations of attention affect the phenomenological experience associated with the retrieval of the memory. Dual process theories posit that there are two forms of recognition memory: one that involves the retrieval of the unique details of the encoding event (recollection), and one that involves the simple mental awareness that an event has been experienced, but lacks any details associated with the memory (familiarity). No study to date has considered whether these two processes are differentially affected by different manipulations of attention at retrieval. By observing how recollective and familiarity-based memory processes are affected by general and material-specific manipulations of attention in younger and older adults, the second study examines the attentional demands of each of these processes, as well as how they are affected by aging. For example, we may suspect that although general manipulations of attention do not disrupt memory performance, they may affect the ability to engage in the process required to retrieve the details of the encoding event involved in recollection, and this may be augmented in older adults, by the loss of resources associated with advancing age. In addition, if the memory deficits experienced during material-specific manipulations of attention are observed in only one of these memory processes (i.e., familiarity), this would suggest that the two processes differ fundamentally in the component processes needed for each. The implications of both studies are then integrated in a general discussion.

Chapter 2
Study 1: Neuroimaging Analysis Using Partial Least Squares

2.1 Introduction to Partial Least Squares Technique and Study

As neuroimaging has become an increasingly popular method used for the study of neural and cognitive processes, a wide variety of techniques have been developed to extract and analyze these rich datasets. In the past, most analyses used univariate techniques, so called because they examine the activity of individual brain voxels. These analyses identify whether the voxels within a particular brain region are more activate during one type of behavioural task than a comparison task. For example, if the voxels positioned in the hippocampal region of the brain show greater activity during a memory, as compared to a visual identification task, we assume that this region is more involved in the cognitive processes relating to memory.

Although these analyses provide valuable information about brain-behaviour relations, cognitive processes are rarely believed to be the result of activation of isolated brain areas. Rather, cognitive processes are thought to result from the integrated activity of brain regions, known as neural networks (Finger, 1994; Friston, 1994; Lashley, 1933). While univariate analysis can identify multiple brain regions that are selectively activated during a particular task, it does not follow that these brain regions are involved in a common network associated with that task, nor does it follow that these networks only involve brain regions identified by the univariate analysis. Such shortcomings have led to the emergence of a new group of imaging methods, known as multivariate techniques.

Multivariate imaging techniques enable researchers to identify the patterns of brain activity that are associated with different tasks and behaviours. The analyses differ from univariate techniques in that they establish relationships between brain voxels. Although several multivariate methods have been developed for the analysis of neuroimaging data (for a review see Petersson, Nichols, Poline, & Holmes, 1999a, 1999b), we will focus on the technique used in the current project, Partial Least Squares (McIntosh, Bookstein, Haxby, & Grady, 1996).

Partial Least Squares (PLS) is designed to examine interactions among brain regions by identifying the optimal relationship between two blocks of data. The first block of data contains all of the functional images for all of the subjects in all experimental conditions. The extensive nature of this data block is the main advantage of this analysis, in that all of the available information of the imaging data is analyzed in a single analytic step. The second block then codes either the experimental design or a behavioural outcome of interest, depending on the type of analysis. The result is a spatial pattern that identifies a group of voxels (or neural network) that best defines the differences in the experimental task or behaviour (a more thorough description of this technique can be found in the methods section of this study).

There are three types of PLS analyses. In order to illustrate the differences between these tasks, I will return to the example of a memory task compared to a visual identification control task. The first analysis, the Task PLS, is used to identify patterns of activity that distinguish the experimental tasks. This analysis would likely show that one pattern of brain activity relates to the memory task, while another pattern relates to the visual identification task, leading us to conclude that different neural networks are recruited to perform the two tasks. The second analysis, the Behavioural PLS, identifies the brain regions that relate to a particular type of behaviour. This pattern may be common across tasks, or task-dependent. For example, if one had measured performance accuracy on the memory and visual identification tasks, the analysis may show a group of brain regions that relate to accurate performance in both tasks, and/or one pattern of brain activity that specifically relates to accurate memory performance and another that relates only to accurate visual identification. The last analysis is the Seed PLS, or functional connectivity analysis. This PLS measures the correlations of activity between a brain region identified by the experimenter and the rest of the brain. For example, if we chose a left prefrontal cortex (PFC) region as a seed, the analysis may find one pattern of brain activity relating to left PFC activity for the memory task, and another pattern relating to left PFC activity for the visual identification task.

This would indicate that although the left PFC is involved in both memory and visual identification tasks, its functional interactions with the rest of the brain differ between tasks.

The PLS method has been used for the study of neural networks in a variety of cognitive domains (for examples see Lenartowicz & McIntosh, 2005; Lobough, Gibson, & Taylor, 2006; McIntosh, Nyberg, Bookstein & Tulving, 1997; Rajah & McIntosh, 2005). Within the study of memory and aging, previous work that has used this technique shows that the spatial patterns relating to experimental tasks or behaviour are different in younger and older adults (Cabeza et al., 1997; Grady et al., 2002; Grady, McIntosh, & Craik, 2005; Tisserand et al., 2005), and that there is a corresponding age-related shift in the brain regions found to predict successful memory performance. While the underlying mechanisms that produce these shifts are unknown, there is a consensus that these changes accumulate throughout the lifespan in response to changes in brain structure and function (Grady, McIntosh, & Craik, 2005).

Multivariate methods have thus come to serve as an excellent compliment to univariate analyses, as both techniques provide different information about how the brain produces behaviour. In the following section I describe how this technique can be used in relation to the study of memory, divided attention, and aging.

2.2 Partial Least Squares Applied to the Study of Memory, Aging, and Divided Attention

The dual-task or divided attention (DA) technique can be used to aid our understanding of cognitive functioning by helping us to infer the type of resources and component processes demanded by a particular task. The divided attention technique works on the assumption that performance on a cognitive task will suffer if it is performed concurrently with a task that uses similar cognitive processes (see Section 1.3). This concept can also be represented at the level of the brain. Since a single brain region cannot perform two neural operations at one time, if two tasks that rely on overlapping brain structures are performed concurrently, performance will be disrupted. Previous researchers have successfully used the technique to demonstrate that if two tasks draw on the same resources (Allport, Antonis, & Reynolds, 1972; Brooks, 1968; Farmer, Berman, & Fletcher, 1986; Robbins, Anderson, Barker, Bradley, Fearneyhough, Henson, Hudson, & Baddeley, 1996), the same hemisphere

(Friedman, Polson, Dafoe & Gaskill, 1982; Klein, Moscovitch, & Vigna, 1973; Moscovitch, 1976; Moscovitch & Klein, 1980; Wickens, 1980), or utilize another common underlying brain structure (Kinsbourne & Hicks, 1978; Klingberg & Roland, 1997; Martin, Wiggs, Lalonde, & Mack, 1994; Moscovitch, 1994), interference will be observed when they are performed simultaneously.

These studies suggest that it is possible to infer which brain regions are preferentially involved on different tests based on the pattern of interference effects created by distracting tasks. If there is competition for common areas or resources, interference is created. An examination of the amount and pattern of interference observed under dual-task conditions may indicate the degree of overlap in cognitive resources, components, and structures required for the two tasks, and can be used to provide insight into human memory processing.

With respect to memory, having participants engage in a concurrent task during encoding leads to larger detriments in memory performance than when attention is divided at retrieval, in both younger and older adults (Anderson, Craik & Naveh-Benjamin, 1998; Baddley et al., 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Nyberg et al., 1997; see Section 1.3). At the level of the brain, functional neuroimaging studies have shown that while activation in the prefrontal cortex (PFC) is reduced by dividing attention during encoding (Fletcher et al., 1995; Iidaka, Anderson, Kapur, Cabeze, & Craik, 2000; Kensinger, Clarke, & Corkin, 2003; Shallice et al., 1994), it is unaffected by dividing attention during retrieval (Anderson et al., 2000; Iidaka et al., 2000).

Specifically, Anderson et al. (2000) used positron emission tomography (PET) imaging to examine whether DA would alter the neural networks engaged during encoding and retrieval in younger and older adults. In their study younger and older adults studied a list of words under full or DA conditions, and later free recalled them under full or DA conditions, with an auditory identification task serving as the distracter task. Replicating previous studies, they found that memory performance was disrupted more by DA conditions during encoding than retrieval. Paralleling these behavioural findings, DA during encoding was found to reduce brain activity in both prefrontal and medial temporal regions, indicating that the attentional manipulation disrupted the neural processes associated with successful memory performance. Conversely, DA at retrieval had relatively little effect on the network used to retrieve information from memory in both younger and older adults. In particular, they found that right prefrontal cortex activity, robust in the FA condition, and associated with memory retrieval processes (Nyberg, Cabeza & Tulving, 1996), was unaffected by their DA condition.

Although retrieval is generally undisrupted during DA, during conditions in which the distracter task contains similar material as the memory task, DA at retrieval can lead to large disruptions in memory performance (Fernandes & Moscovitch, 2002; 2002), (see Section 1.3). Examining this exception can shed light on the processes critical for successful retrieval. Fernandes and Moscovitch (2000, 2002) found that verbal memory retrieval is disrupted if it is performed concurrently with a word-based distracter task (a material-specific manipulation of attention), but not a digit-based distracter task (a general manipulation of attention). In order to examine how general and material-specific manipulations of attention are manifested at the level of the brain, Fernandes, Pacurar, Moscovitch, and Grady (2006) used fMRI to examine the neural activity of younger and older adults during a memory recognition test performed under FA, compared to recognition performed concurrently with an odd-digit identification task to numbers (DA-digit), or an animacy decision task to words (DA-word). They found that, in the younger adults, right hippocampal activity was significantly reduced during the DA-word, compared to DA-digit and FA conditions, though there were no differences across DA tasks in PFC activation. These results support the hypothesis from the component-process model (see Section 1.3), which states that material-specific competition arises from competition for processes involved in reactivation of the memory trace rather than competition for general attentional resources.

Older adults, however, showed a different pattern of activity. During recognition under FA, older adults had more activity in bilateral dorsolateral prefrontal cortex (PFC). These findings are in line with previous work showing that older adults have greater activity in left PFC during retrieval than younger adults, who instead generally show right lateralized activity (Anderson et al., 2000; Bäckman et al., 1997; Cabeza, Anderson, Houle, Mangels & Nyberg, 2000; Grady et al., 2002; Madden et al., 1999).

There were, however, two unexpected findings in the Fernandes et al (2006) study. First, during both DA conditions, older adults showed greater activity in posterior neocortex compared to the younger group, and second, older adults did not modulate hippocampal activity across DA conditions, as did the younger adults. This second finding is in line with recent work suggesting the role of the hippocampus in memory retrieval changes with age (Cabeza et al., 2004; Grady et al., 2005; Tisserand et al., 2005). These unexpected findings suggest that older adults may be achieving memory by a) recruiting different brain structures than young adults, or b) approaching the recognition task with a wholly different strategy than younger adults, leading to recruitment of different brain regions.

While the findings of Fernandes et al. (2006) can inform us about the neural substrates active during certain DA conditions, they do not tell us how the brain, as a whole, changes dynamically to achieve performance under various DA conditions. In the current study, we applied a multivariate imaging analysis technique, Partial Least Squares (PLS), to the Fernandes et al. (2006) dataset in order to examine commonalities and differences in the networks engaged during FA and DA retrieval across age groups. We performed three types of multivariate analyses that allow us to address three different questions. The first analysis, a Task PLS, was used to identify the patterns of brain activity that differentiated the experimental tasks (FA, DA-digit, and DA-word). If material-specific, but not general, manipulations of attention interfere with the network used to guide memory retrieval, we would expect the FA and DA-digit conditions to be associated with different networks of activity than the DA-word condition, in both younger and older adults. In addition, since memory performance does not differ between the FA and DA-digit conditions, we expected that these conditions would use similar neural networks during memory retrieval. In particular, we expected to see little or no difference in right prefrontal activity, in the DA-digit compared to FA condition, in younger and older adults, replicating Anderson et al. (2000).

We next performed a Behavioural PLS to determine whether the pattern of brain activity associated with successful memory performance changed under FA compared to DA conditions, and whether these changed with age. Although general manipulations of attention show minimal effects on the brain activity relating to memory retrieval (Anderson et al., 2000), there may be a shift in how these brain regions relate to successful memory performance under DA. Alternatively, the patterns of brain activity relating to successful memory performance may mirror behavioural performance, such that the pattern will be similar in the FA and DA-digit conditions, but different in the DA-word condition, in which memory interference is observed.

In addition, there has been some debate as to how to interpret the pervasive finding, in neuroimaging studies, of increased bilateral PFC activity in older adults. Some work has found that increased activity is associated with improved memory performance in older adults (Cabeza, Anderson, Locantore, & McIntosh, 2002; Madden et al., 1999), leading to the suggestion that the additional activity serves a compensatory role (Cabeza et al., 2002; Gutchess et al., 2005; Grady et al., 2002). Other studies have failed to find this result (Daselaar, Veltman, Rombouts, Raaijmakers, & Jonker, 2003), and have suggested that the increased activity is non-selective, and reflects deficits in inhibitory processing with old age (Logan, Sanders, Snyder, Morris, & Buckner, 2002). In the current study we examined whether left PFC activity was more strongly positively related to memory performance in older, as compared to younger, adults.

Lastly, we performed a Seed PLS, to assess the functional connectivity of the hippocampus, with other brain regions. This analysis was performed to examine whether the role of the hippocampus, and its connections change with advancing age, and also, to test claim that during material-specific memory interference, there is a disruption in the ability of the hippocampus to index the content of the memory trace (Fernandes et al., 2006). The latter claim would be supported if the analysis showed that a neural network relating to hippocampal function is used to reactivate the content of the memory trace during the FA and DA-digit, but not DA-word, conditions. In addition, in the Fernandes et al. (2006) study, only younger adults showed diminished hippocampal activity in the DA-word condition, in which memory was poor, compared to hippocampal activity in the DA-digit and FA conditions, in which memory was good. As such, it may be that the relationship of the hippocampus with other regions plays a greater role in determining memory success in younger than older adults.

2.3 Partial Least Squares Methods and Results

2.3.1 Methods

Details of the procedure used in the Fernandes et al. study are also noted in that publication, and relevant sections are included below.

Participants.

Twelve healthy younger adults (7 female; 2 left handed), from 20 to 30 years of age (mean age = 26.33, SD = 3.36), and 12 healthy older adults (8 female; 1 left-handed) from 65 to 76 years of age (mean age = 71.18; SD = 4.07) participated in the study. Data from one male, left-handed senior was excluded due to excessive head movement during scanning. Younger adults had a mean of 17 years (SD = 2.33) of education and older adults had a mean of 16.4 years (SD = 4.07). In order to compute an estimate of full scale IQ, the National Adult Test of Reading (NART-revised; Nelson, 1982; Blair & Spreen, 1989) was administered to all participants. Younger adults had a mean FSIQ of 114.3 (SD = 2.16) and older adults a mean of 113.5 (SD = 8.2). All procedures were approved by the ethics committee of Baycrest Centre for Geriatric Care. All participants spoke English fluently and were free from psychiatric or neurological disease. Of the older adults, one participant was taking cholesterol-reducing medication, one was taking thyroid medication, two were taking medication to reduce high blood pressure, and two were taking calcium supplements at time of testing.

Behavioural task materials.

Word stimuli for the recognition and word distracter tasks consisted of medium to high frequency words chosen from Francis and Kucera (1982), with word frequencies ranging from 20-100 occurrences per million. During each study phase, participants heard a list of 50 unrelated words, presented via Avotec headphones, while in the scanner. Words were presented at a rate of 1 word every 2 seconds. During the recognition phase, participants once again heard words and made a button press if the word was ‘old’. The presentation volume was adjusted for each individual participant prior to the study phase, so that the items were heard clearly over the noise produced by the scanner.

Items in the distracting tasks were presented visually, with black letters or numbers on a white background. The items were shown centrally through MRI compatible goggles (Silent Vision™, Avotec Inc.), with the acuity adjusted for each participant. Items for the word task were visually presented words (mean of 6 letters), representing animals (e.g. kitten) or man-made objects (e.g. hammer). Participants made a button press when presented with a man-made item. Items for the odd-digit task were two-digit numbers flanked by two Xs on either side, chosen from a table of random numbers (Kirk, 1995). Participants made a button press when the visually presented digit was odd. In each block, half of the items required a button-press and the items were presented randomly at a rate of 1 item every 2 seconds.

The study also included two control tasks. The first was an auditory control task, in which participants heard either the word “word” or “press”, and made a button-press for the later. The second was a visual control task, wherein participants saw either a string of “OOOOOO” or “XXXXXX”, and made a button-press for the latter. For the auditory tasks, participants responded with their index finger of the left hand, and for the visual tasks, participants responded with the index finger of the right hand, using two fMRI-compatible response pads (Lightwave Technologies, Surrey, BC, Canada).

Procedure.

Stimulus presentation and response recording were controlled by an IBM PC, using E-prime v.1.0 software (Psychology Software Tools Inc., Pittsburgh, PA). Participants first performed a practice session, consisting of a block of each single and dual task conditions, outside of the scanner. This was followed by a sample run, in which blocks were presented randomly, as in the scanner. Blocks during both the practice and scanner sessions began with 4 seconds of short instructions followed by the presentation of 10 items at a rate of 1 item every 2 seconds, making each block 24 seconds long. For the dual-task conditions, the auditory recognition and distracting task items were presented simultaneously. For the auditory recognition tasks, half of the words were old (5 targets per block), and in each of the distracting tasks, half of the items were targets (5 targets per block).

Prior to each of the 4 scanning runs, and while in the scanner, participants heard a study list of 50 unrelated words. Encoding was not scanned. Participants then counted backwards silently by threes for 30 seconds, followed by the scanning runs. Each participant performed two “short” scanning runs, consisting of 7 blocks presented pseudorandomly: 3 recognition tasks performed under full attention (FA), 2 recognition tasks performed with the word distracting task (DA-word), and 2 of the recognition tasks performed with the odd-digit task (DA-digit). The FA blocks were presented in between the DA blocks. Participants also performed two “long” scanning runs, consisting of 19 blocks presented pseudorandomly: 2 of the word task performed alone, 2 of the odd-digit task performed alone, 2 of the FA recognition task, 2 of DA-word, 2 of the DA-digit, 5 of the auditory control task, and 4 of the visual control task. Blocks of the visual and auditory control tasks alternated between the other tasks. The order of runs alternated between short and long, with presentation counterbalanced across participants.

Long runs were included in order to compare single to dual task performance, and the short runs were included in order to keep the delay between encoding and recognition similar to previous studies (Fernandes & Moscovitch, 2000, 2002, 2003). However, for the present analysis, we included only the FA condition, the two DA conditions, and the auditory control task.

<u>fMRI Data Acquisition.</u>

Data were acquired with a Signa 1.5 Tesla magnet with a standard coil (CV/i hardware, LX8.3 software; General Electric Medical Systems, Waukesha, WI). Functional imaging was performed to measure brain activation by means of the blood-oxygenated level-dependent (BOLD) effect (Ogawa et al., 1990) with optimal contrasts. Functional scans were acquired with a single-shot T2*-weighted pulse sequence with spiral readout (axial orientation, TR = 2500 ms; TE = 40 ms; flip angle = 80°; effective acquisition matrix = 64 x 26; FOV = 20 cm; number of slices = 26; slice thickness = 5.0 mm; slice spacing = 0). Reconstruction of the data was conducted off-line and included gridding (Glover & Lai, 1998) and correction for magnetic field inhomogeneites and Maxwell gradient terms. For each participant, two short runs of 76 volumes each and two long runs of 191 volumes each were collected.

A standard high-resolution, 3D T1-weighted fast spoiled gradient echo image (axial orientation; TR = 35 ms; TE = 6.0 ms; flip angel = 35°; acquisition matrix = 256 x 124; FOV = 22 x 16.5 cm; number of slices = 124; slice thickness = 1.4 mm; slice spacing = 0) was obtained before fMRI acquisition and used to register brain structure and function.

fMRI Data Analysis.

We used partial-least squares (PLS) analysis (McIntosh et al., 1996) to analyze the data. PLS is a multivariate analysis method that has recently been adapted to analyze neuroimaging data, and is based on the assumption that cognitive processes result from the activity of an integrated neural network, rather than the activation of any independent brain region. PLS analyses are used to identify patterns of brain activity that co-vary with either some aspect of the experimental design or behavioural measure. The analysis first computes the cross-covariance between two matrices, one that codes either the experimental design (Task PLS) or a measure of performance (Behaviour/Seed PLS), and one that contains values for each voxel of each scan of each cognitive task. This cross-covariance matrix is then decomposed using singular value decomposition, in order to identify latent variables (LV), or orthogonal patterns of brain activity. The LVs are ordered such that the first LV represents the greatest amount of cross-covariance between the two sets of measurements, and successive LVs account for progressively less cross-covariance. Within each LV, each voxel is given a positive or negative value (or salience), which represents how that voxel is related to the LV. These values are then multiplied by the individual images of each task for each participant and summed across the voxels in order to derive an estimate of how robustly each participant displays that spatial pattern (a ‘brain score’). The different tasks or behaviours are also given a ‘task score’, which can also be positive or negative, which identifies how strongly that particular task (or behaviour) is related to the positively or negatively weighted voxels of that LV.

PLS uses two different methods to test for statistical significance. First, the LV is statistically assessed using permutation tests (Edgington 1980; McIntosh et al. 1996). We used 500 permutations and a statistical cut-off of $p < .05$. Secondly, the reliability of how each brain voxel contributes to the LV is determined by bootstrap estimation (Efron & Tibshirani 1986). This technique produces a bootstrap ratio (BSR: the ratio of the salience of the voxel to the standard error of that salience), and an associated approximate p-value. We used 100 bootstrap estimations and a cut-off of a BSR of 4, which gives an approximate p-value of 0.0001. In addition, for these analyses, a cluster was defined as having a minimum size of 30 contiguous voxels and minimum distance of 1mm apart.

Since PLS identifies brain coordinates using the Montreal Neurological Institute (MNI) space, all coordinates resulting from the PLS analyses were converted to Talairach and Tournoux (1988) coordinates using the algorithm developed by Brett and colleagues (http://www.mrc-cbu.cam.ac.uk/Imaging/Common/mnispace.shtml). Brain structures were then located using the Talairach and Tournoux (1988) atlas.

We performed three different types of PLS analyses on the data from the FA, DA-digit, and DA-word task conditions. We first performed a Task PLS analysis on the younger and older adult data separately. This allowed us to identify age-specific networks of activity that differed according to memory condition (FA, DA-digit DA-word).

Secondly, we performed a Behavioural PLS on both the younger and older adult data in order to identify the age-related changes in the neural networks associated with accurate memory performance during the three memory conditions. This analysis identified brain regions that positively or negatively co-vary with memory accuracy (measured as hit rate – false alarm rate) in the FA, DA-digit, and DA-word conditions.

Lastly, we performed a Seed PLS, which is a variation of the Behaviour PLS (see McIntosh, Chau & Protzner, 2004), to examine the functional connectivity of the hippocampus (i.e., how the activity in this brain region co-varies with activity in the rest of the brain) in younger and older adults. For this analysis, we used a hippocampal region (x, y, z = 33, -27, -9) that showed greater activity during the DA-digit than the DA-word condition in the younger adults only (Fernandes et al., 2005). We then considered whether the pattern of functional connectivity with the hippocampus covaries with behaviour by including memory accuracy data in the analysis. This analysis allowed us to identify a) whether and how a memory network related to hippocampal function changes under conditions of DA, b) how this network relates to memory accuracy, and c) how the role of this network changes with age.

2.3.2 Results

Behavioural Results.

Memory Task.

Recognition performance was calculated, for each block, as the proportion of hits minus the proportion of false alarms. The resulting recognition accuracy score was then averaged across all similar block types (FA recognition, DA -word, DA-digit, see Table 1 for means).

Table 1
Recognition Task Performance in Full and Divided Attention Conditions

	Full Attention		DA-word		DA-digits	
Measure	Young	Old	Young	Old	Young	Old
Hit Rate	.67 (.13)	.57 (.16)	.55 (.11)	.41 (.17)	.64 (.18)	.56 (.14)
False alarm rate	.10 (.04)	.19 (.09)	.17 (.06)	.20 (.12)	.10 (.05)	.21 (.12)
Accuracy	.57 (.14)	.38 (.14)	.38 (.15)	.21 (.11)	.55 (.20)	.35 (.11)
RT	1114 (66)	1180 (120)	1271 (68)	1262 (145)	1182 (62)	1292 (125)

Note: DA = divided attention; RT = reaction time in milliseconds
Accuracy = hit rate – false alarm rate; Standard deviations shown in parentheses.

Also shown (in Table 1) are the mean reaction times for correctly recognized words. Recognition accuracy data were analyzed using a within-subject (FA, DA-digit, DA-word) ANOVA, with Age group as a between subject factor. There was a main effect of Recognition condition, $F(2, 42) = 27.34$, $p < .001$. Post hoc t-tests showed that recognition during DA-word was lower than that during both FA, $F(1, 21) = 57.25$, $p < .001$, and DA-digit, $F(1, 21) = 34.31$, $p<0.001$. Recognition during DA-digit did not differ from that under FA, $F(1, 21) = 1.06$. There also was a significant age effect, $F(1, 21) = 12.82$, $p = 0.002$, with older adults recognizing fewer words than young adults, but the Age x Recognition condition interaction was not significant.

To determine the degree of interference in the two DA conditions, we also analyzed the percentage decline in performance in the DA relative to FA condition for each participant (see Figure 1). On this measure, there was a significant effect of DA condition, $F(1, 21) = 19.15$, $p<0.001$, indicating that memory interference was greater in the DA-word compared to DA-digit condition. However, neither the effect of age nor the interaction of age and condition was significant, indicating that younger and older adults experienced memory interference of equivalent magnitudes in both DA conditions.

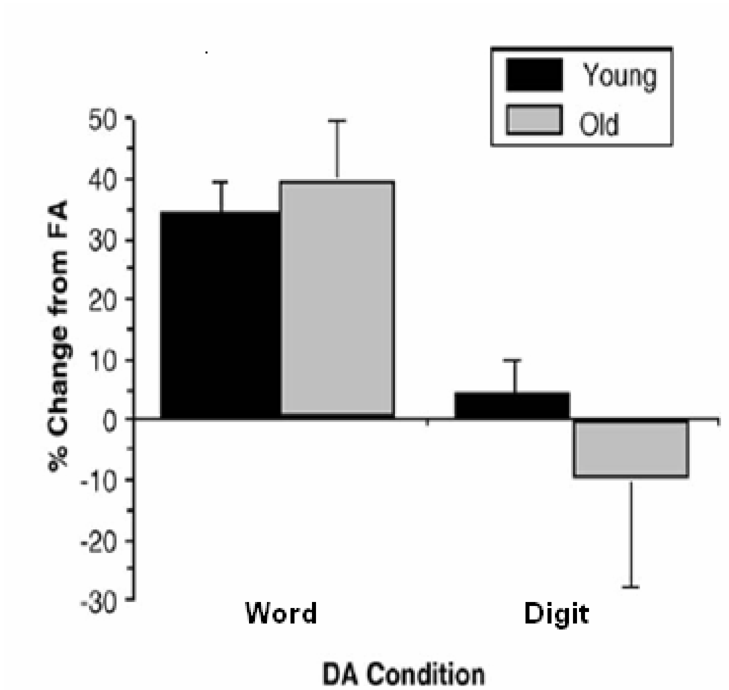

Fig. 1. Percent change in memory performance accuracy from FA during the DA digit and DA word conditions in younger and older adults. Error bars represent the standard errors.

In terms of reaction time (RT), there was a significant effect of Recognition condition, $F(2, 42) = 14.35$, $p < .001$ (Table 1). Planned comparisons showed that RTs during FA were faster than either during DA-word or DA-digit, $F(1, 21) = 21.32$ and 21.66 respectively ($p<0.001$), though there was no difference in recognition RT across the DA conditions. There was a trend for older adults to be slower to respond, $F(1, 21) = 2.88$, $p = .10$. In addition, the interaction of Age group x Recognition condition was significant, $F(2, 42) = 3.40$, $p <0.05$. Post hoc contrasts indicated that the old adults had significantly slower RTs only for the DA-digit condition, $t(21) = -2.73$, $p < 0.05$.

Performance data on each distracting task was also collected and analyzed, and are reported in Fernandes et al. (2006). These results are not repeated here as they are not pertinent to the focus of the current study.

fMRI Results.

Task PLS.

Younger Adults.

The Task analysis, on the younger adult data, revealed a significant LV (p = .02), and identified networks differentially associated with the FA and DA-digit conditions (see Figure 2).

The FA condition was related to a network of left medial frontal, left parahippocampal, right anterior cingulate, right postcentral, bilateral precentral, right putamen, right caudate, left cuneus, and left cerebellar (culmen) regions (see Table 2 and Figure 3: orange regions). Conversely, the DA-digit condition was associated with one region of activation in the right superior frontal cortex (see Figure 3: blue regions). There was no significant pattern associated with the DA-word condition.

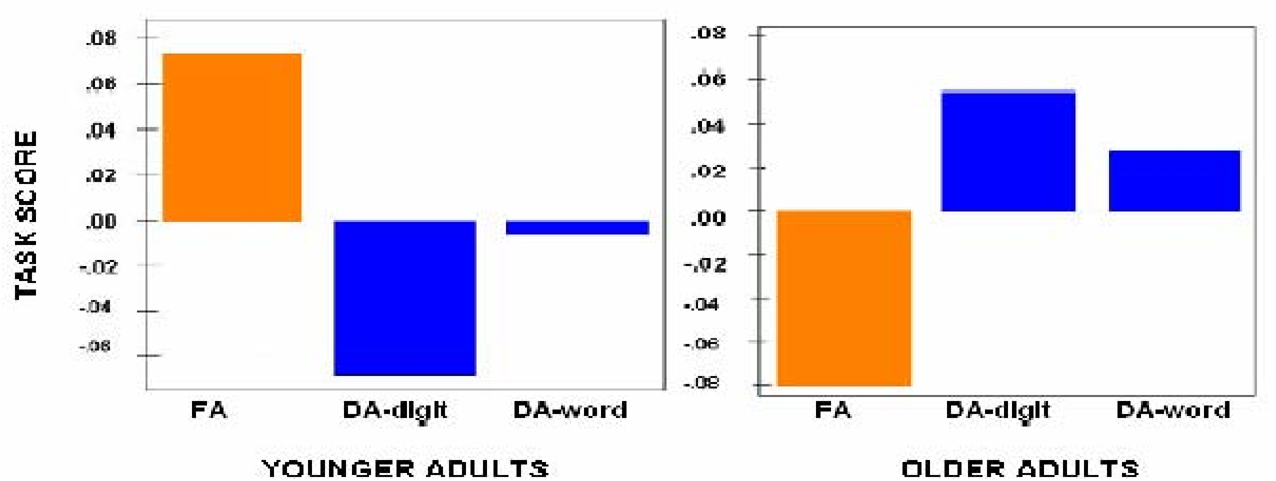

Fig. 2. Strength of association between the three memory conditions and the identified neural network in younger (left) and older (right) adults. Note: FA = full attention, DA = divided attention.

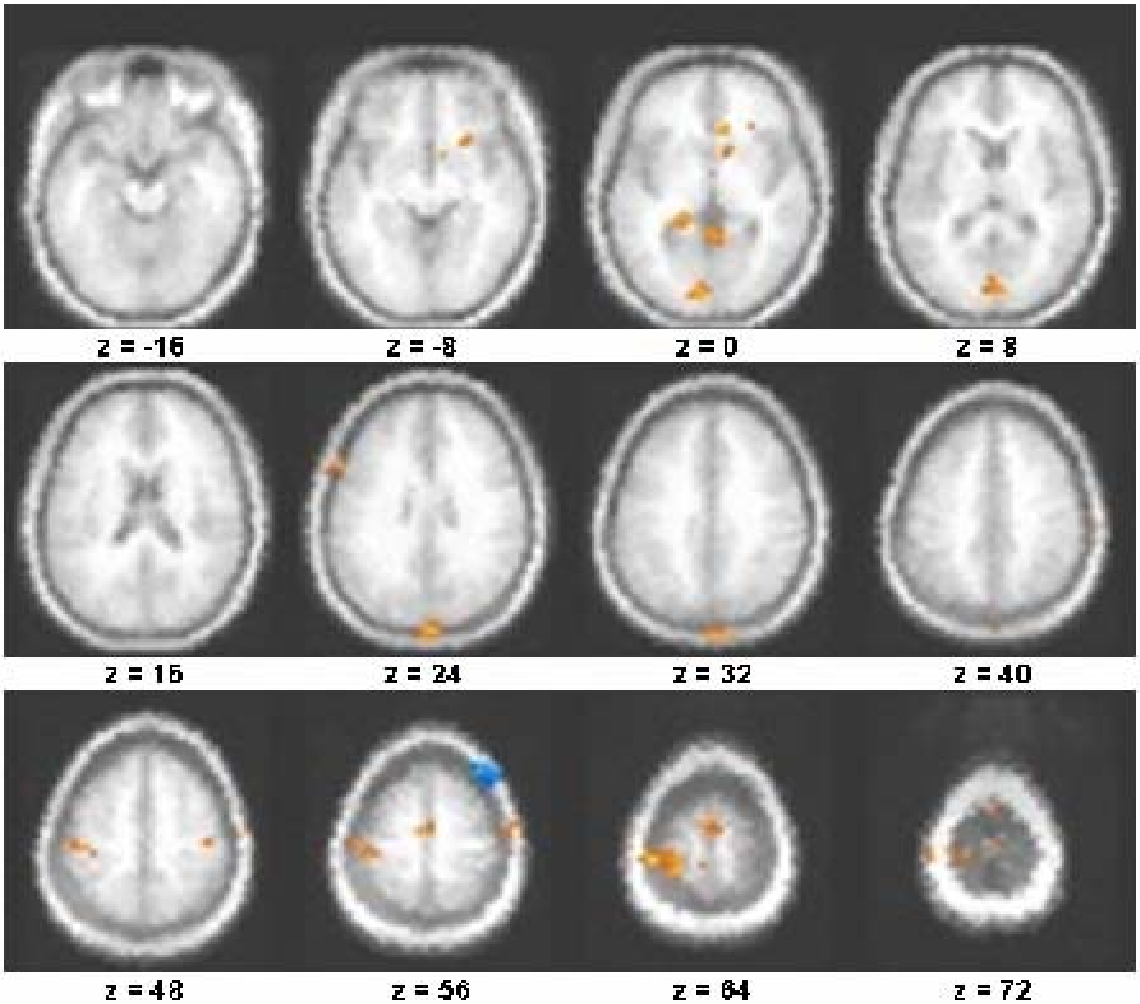

Fig. 3. Regions of reliable task-related activity in younger adults are shown on representative slices of the average structural MRI of the younger adults re-sampled into MNI space at the indicated Z levels relative to the AC-PC line (anterior-commissure-posterior commissure line). The right side of the brain is shown on the right side of the image. Areas shown in orange represent the brain network related to the FA condition, and those shown in blue represent the network related to the DA-digit condition.

Table 2

Brain areas with differential activity in the FA and DA-digit condition in the younger adults.

Region, gyrus	Hem	BA	X	Y	Z	Ratio
FA > DA-digit						
Postcentral	L	3	-24	-28	64	9.07
Putamen	R		22	15	-4	8.23
Parahippocampus	L	27	-22	-35	-2	8.01
Cuneus	L	17	-8	-81	6	7.81
Caudate Head	R		10	10	3	6.95
Anterior Cingulate	R	24	6	27	-1	6.72
Culmen	L		0	-47	-1	6.16
Medial Frontal	L	6	-8	-5	57	6.14
Precentral	R	4	38	-19	49	5.75
Precentral	R	6	53	-4	35	5.47
Postcentral	R		51	-11	52	5.14
Medial Frontal	L	6	-6	-20	64	5.08
DA-digit> FA						
Superior Frontal	R	8	32	32	50	-9.11

Note: FA: full attention; DA: divided attention; the Talairach coordinates represent the peak for the given region; Hem: hemisphere; R: right; L: left; BA: Brodmann's Area according to the atlas of Talairach and Torunoux (1988); Ratio: salience/standard error; X (right/left): negative values are in the Left Hemisphere; Y (anterior/posterior): negative values are posterior to the zero point (located at the anterior commissure); Z (superior/inferior): negative values are inferior to the plane defined by the anterior and posterior commissures.

Older Adults.

The Task analysis performed on the older adult data identified a significant LV ($p = .008$) which identified two different networks, one used for the FA condition, and one used during both the DA-digit and DA-word conditions. Under FA, a network consisting of right anterior cingulate, left parahippocampal, right superior temporal, right lingual, left middle occipital, and left subcallosal regions was identified (see Table 3 and Figure 4: orange regions). Conversely, the DA conditions recruited a network consisting of bilateral middle frontal, left fusiform, right postcentral, and left anterior cingulate regions (see Figure 4: blue regions).

Table 3

Brain areas with differential activity in the FA and both the DA-digit and DA-word conditions in the older adults.

Region, gyrus	Hem	BA	X	Y	Z	Ratio
DA > FA						
Middle Frontal	L	46	-50	40	24	8.73
Fusiform	L	37	-46	-38	-15	8.12
Middle Frontal	R	9	32	31	37	7.31
Postcentral	R	43	68	-19	16	6.84
Anterior Cingulate	L		-18	30	11	6.51
FA > DA						
Anterior Cingulate	R		8	9	-8	-9.56
Cuneus	L	17	-6	-83	10	-9.18
Middle Occipital	L	18	-22	-92	16	-7.29
Subcallosal	L	25	-12	21	-14	-7.19
Superior Temporal	R	38	40	10	-32	-6.14
Lingual	R	19	24	-68	-2	-5.72
Parahippocampus	L		-20	-57	-4	-5.63

Note: FA: full attention; DA: divided attention; the Talairach coordinates represent the peak for the given region; Hem: hemisphere; R: right; L: left; BA: Brodmann's Area according to the atlas of Talairach and Torunoux (1988); Ratio: salience/standard error; X (right/left): negative values are in the Left Hemisphere; Y (anterior/posterior): negative values are posterior to the zero point (located at the anterior commissure); Z (superior/inferior): negative values are inferior to the plane defined by the anterior and posterior commissures.

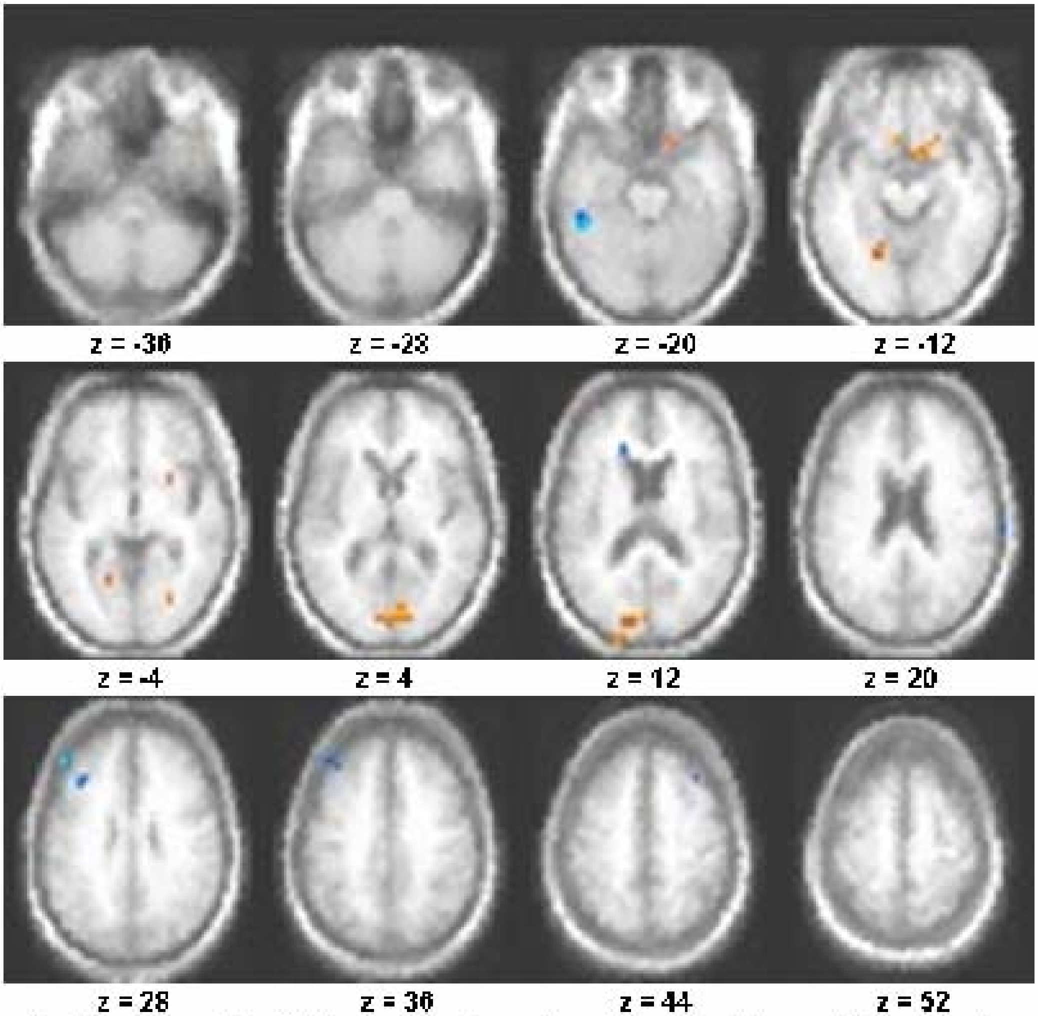

Fig. 4. Regions of reliable task-related activity in older adults are shown on representative slices of the average structural MRI of the older adults re-sampled into MNI space at the indicated Z levels relative to the AC-PC line (anterior-commissure-posterior commissure line). The right side of the brain is shown on the right side of the image. Areas shown in orange represent the brain network related to the FA condition, and those shown in blue represent the brain network related to the DA-digit and DA-word conditions.

Behavioural PLS.

Younger Adults.

A marginally significant LV ($p < 0.07$) identified brain regions that co-varied with accuracy in the FA and DA-digit condition, and less so for the DA-word condition (as indicated by the 'task score'; see Figure 5). Brain regions found to be positively correlated with memory accuracy were found in the right medial frontal, left middle frontal, left inferior frontal, left superior frontal, bilateral cingulate, right precuneus, and bilateral sub-lobar regions (see Figure 6: orange regions).

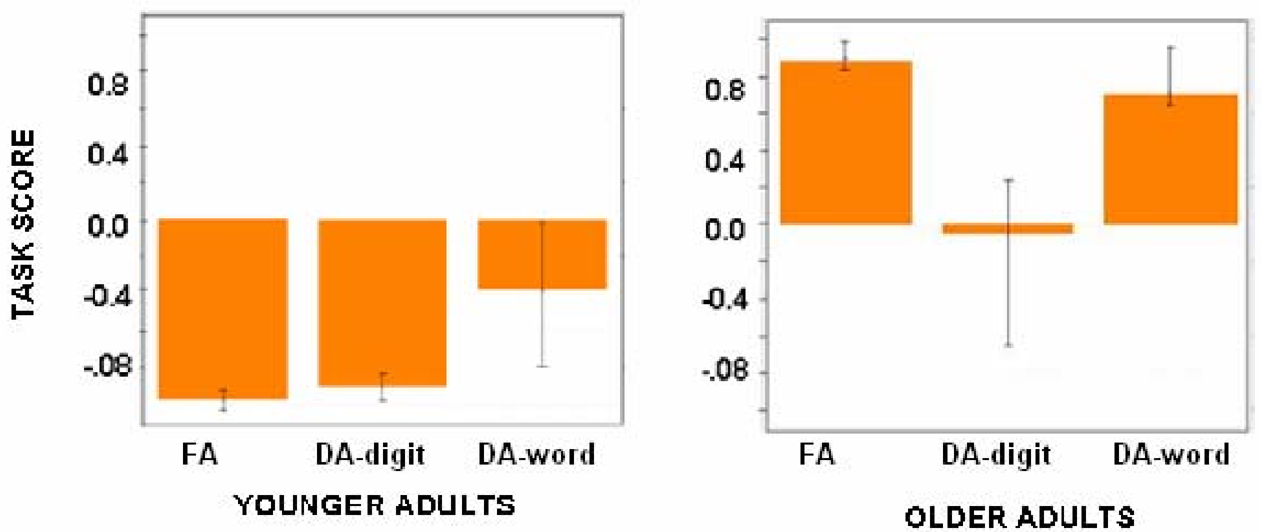

Fig. 5. Strength of association between the identified neural network and recognition accuracy for each memory condition for younger (left) and older (right) adults. Note: FA = full attention, DA = divided attention.

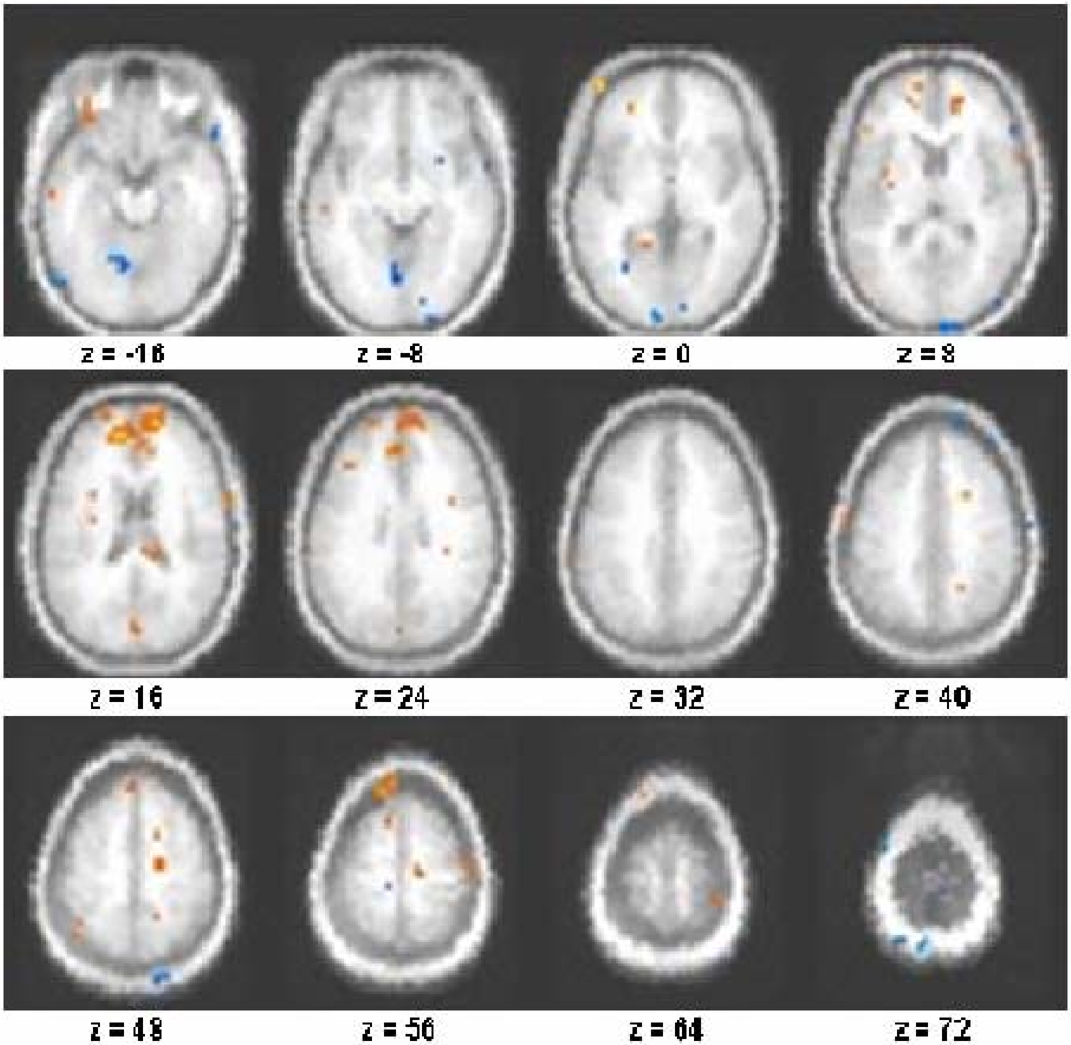

Fig. 6. Neural networks of activity related to recognition accuracy (hit rate – false alarm rate) in younger adults. Regions in orange represent the network positively associated with recognition accuracy.

Older Adults.

For the older adults, a LV relating to memory accuracy was marginally significant ($p = .052$), which identified regions that positively co-varied with memory performance in the FA and DA-word conditions, but not the DA-digit condition (see Figure 5). Regions found to co-vary positively with memory accuracy in the FA and DA-word conditions were in bilateral superior frontal, right parahippocampal, right caudate, and left sub-lobar regions (see Figure 7: orange regions).

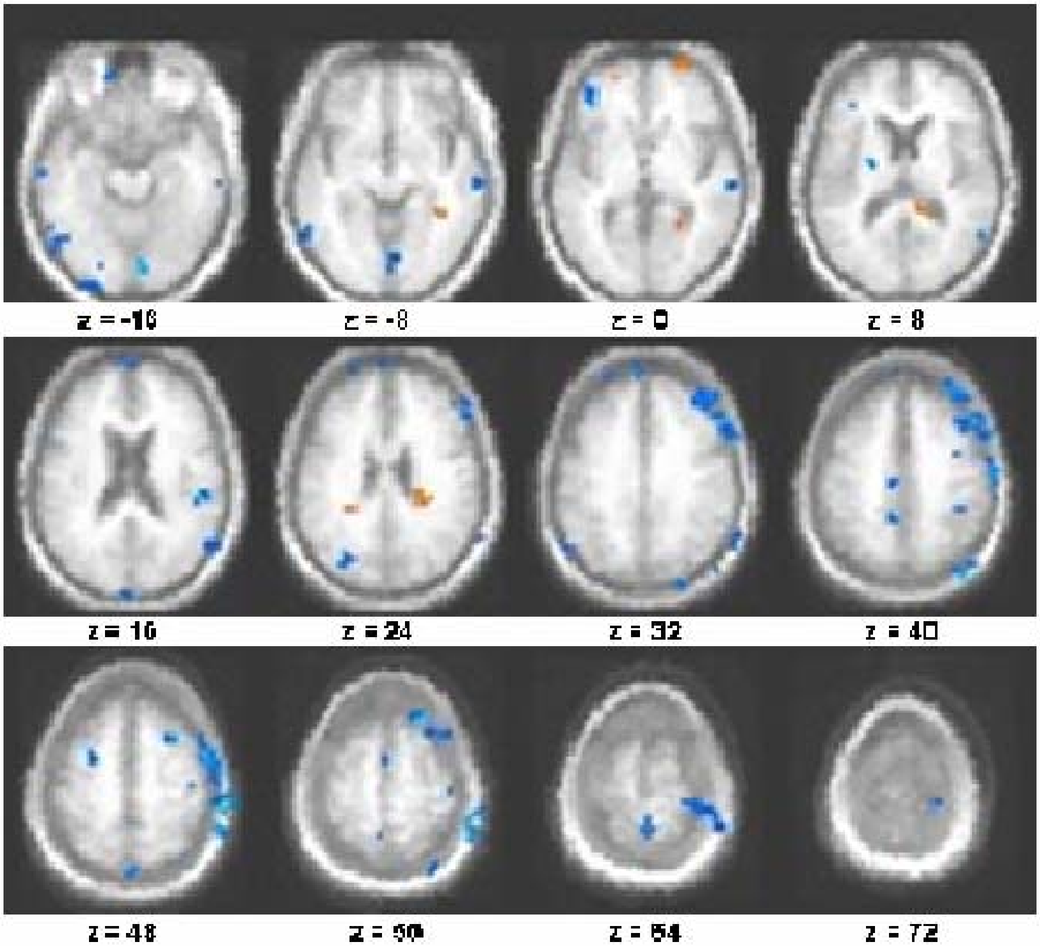

Fig. 7. Neural networks of activity related to recognition accuracy (hit rate – false alarm rate) in older adults. Regions in orange represent the network positively associated with recognition accuracy.

Seed PLS (Functional Connectivity of Hippocampus).

Younger Adults.

The functional connectivity analysis identified one significant LV (p = .01) which identified a network of regions that co-varied with activity in the hippocampus seed, including bilateral middle and medial frontal, left superior and inferior frontal, right hippocampal, right inferior parietal, right precuneus, right precentral, left superior and medial temporal, as well as bilateral cingulate regions (see Figure 9: orange regions). This network was activated in all three memory conditions, although the 'task score' was lower in the DA-word condition. In addition, this network co-varied with accurate memory performance in the FA and DA-digit conditions (see Figure 8). In contrast, memory accuracy for the DA-word condition was associated with a different spatial pattern (see Figure 8), that identified only one brain region of activity, in the left precuneus (see Figure 9: blue regions).

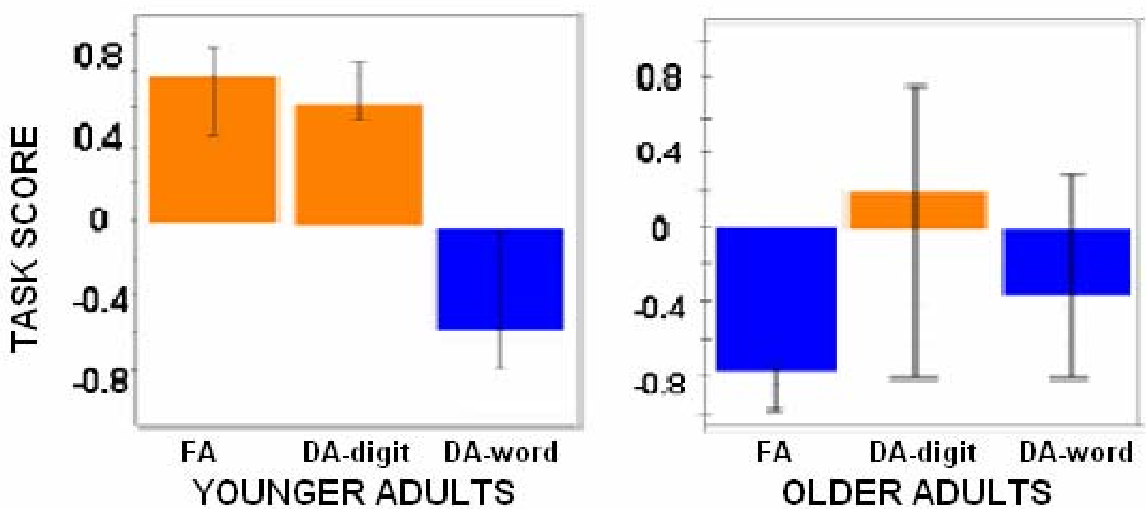

Fig. 8. Strength of association between the functional network and recognition accuracy during each memory condition for the younger (left) and older (right) adults. Note: FA = full attention and DA = divided attention.

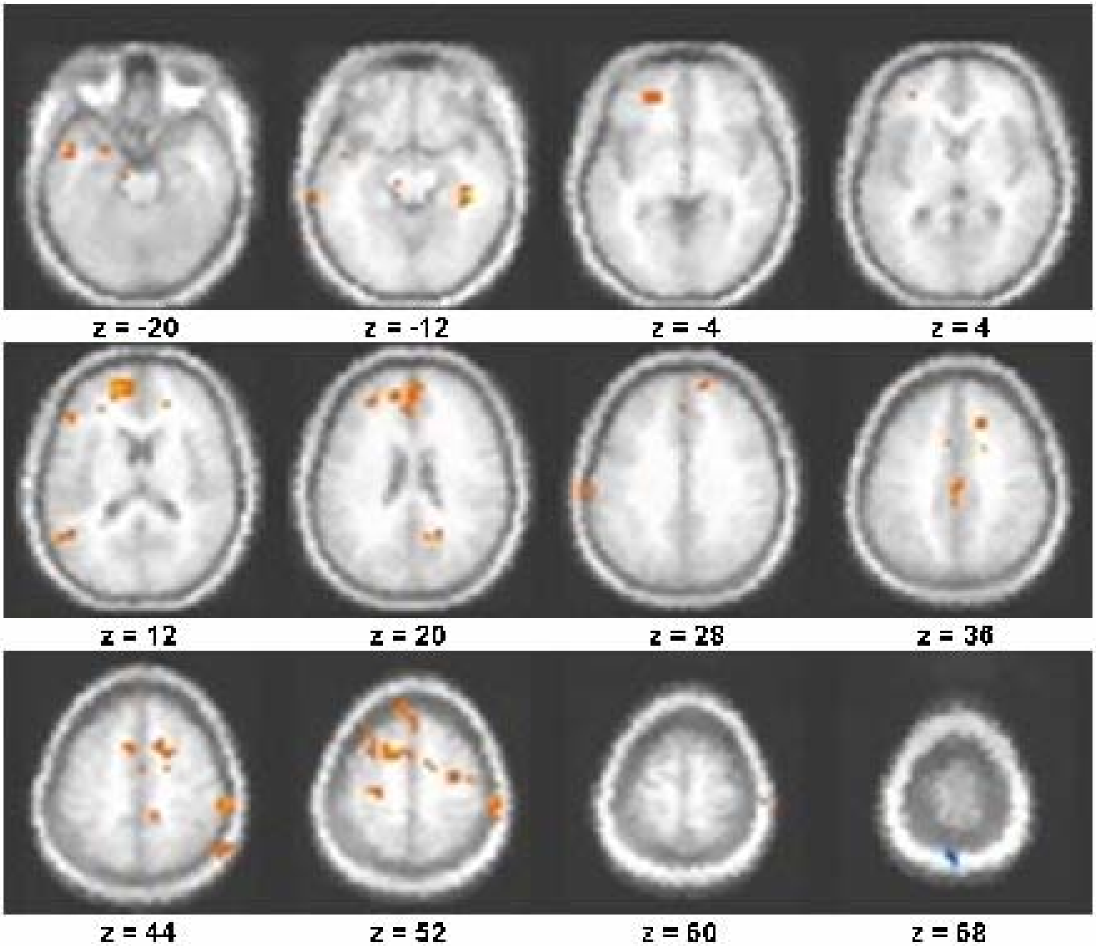

Fig. 9. Images of the functional connectivity of the right hippocampus reference regions for the younger adults. Brain areas shown in orange are associated with all three memory conditions and recognition accuracy during the FA and DA-digit conditions, whereas brain areas shown in blue are associated with recognition accuracy during the DA-word condition.

Older Adults.

One spatial pattern correlating with activity in the hippocampus seed region was significant (p <.001). This identified a network including right middle and superior frontal, right precentral, left postcentral, right hippocampal, right middle and left inferior temporal, right inferior and superior parietal, left middle occipital, right angular, left supramarginal, bilateral cuneus, right cingulate, and left cerebellar regions. All three memory conditions, as well as memory accuracy in the DA-digit condition, were associated with this network; however, the standard errors around the 'task' scores were generally large, indicating that the pattern is not reliable across participants (see Figure 8). There were no significant brain regions relating to activity in the hippocampus seed that co-varied with memory accuracy in the FA and DA-word condition.

2.4 Partial Least Squares Discussion

We used PLS to identify networks of brain activity related to memory retrieval in younger and older adults under full and divided attention conditions. Replicating previous work (Fernandes & Moscovitch, 2000, 2002, 2003), we found that the word-based distracter task interfered with memory performance to a greater degree than the digit-based distracter task. Although older adults showed poorer memory performance overall, the magnitude of material-specific interference was equivalent in younger and older adults.

The multivariate Task PLS analyses showed that the neural networks used to support memory retrieval under FA and DA-digit conditions are roughly similar in younger and older adults, and that these networks were relatively unaffected by general manipulations of attention. Such a finding is in line with Anderson et al. (2000). The Behavioural PLS analyses showed that in younger adults, memory performance in both the FA and DA-digit conditions was related to increases in right medial frontal, left middle, inferior, and superior frontal regions, as well as the right precuneus, but that in older adults there was no pattern of activity related to behavioural performance. Lastly, the Seed PLS showed that the functional connectivity of the hippocampus, as well as how activity in this network relates to memory performance, differed with age. Each of these results is discussed in turn.

Task-Related Networks in Younger and Older Adults

The task PLS differentiated the FA and DA-digit conditions in both younger and older adults (see Figure 1). Since the DA-word condition was not strongly associated with either network, this supports the hypothesis that during material-specific interference, there is a disruption in the processing usually engaged during retrieval.

The differences in patterns of brain activity during the FA and DA-digit conditions were generally the same in younger and older adults. Importantly, replicating Anderson et al. (2000), we found that neither younger or older adults showed reduced right prefrontal cortex activity during the DA-digit condition, and somewhat surprisingly, found that younger and older adults had additional activity in this region under DA conditions (see Figure 4). Activation in the right PFC is found during most studies of memory retrieval (Nyberg, Cabeza & Tulving, 1996), and has been framed in terms of post-retrieval processing (Rugg et al., 1996), retrieval mode (Tulving, Kapur, Craik et al., 1994; Lepage et al., 2000), or monitoring and verification processes (Henson, Shallice & Dolan, 1999; Cabeza, Lacantore & Anderson, 2003). Our findings indicate that the involvement of this region is unaffected during general manipulations of attention in younger and older adults, and may actually increase in older adults to cope with increased processing demands.

We also found that during DA, older adults additionally recruited a left ACC and left middle PFC region (see Figure 3). Activation in the ACC is believed to be involved in the monitoring or detection of response conflict (Banich et al., 2001; Carter, 1998) and may be involved in attentional and cognitive control functions during memory retrieval (Cabeza et al., 2003; Badre & Wagner, 2004). Additionally, the left PFC has been associated with controlled processing functions during retrieval, as indicated by studies that manipulate the effort required to retrieve an item from memory (Achim & Lepage, 2005; Badre, Poldrack, Paré-Blagoev, Insler & Wagner, 2005; Lepage, 2003; Moss et al., 2005; Velanova et al., 2005; Wheeler & Buckner, 2003) This suggests that the increased activity in these regions may also reflect the need for additional attention and executive processing functions during DA at retrieval in older adults. This finding concurs with the behavioural findings, in that older adults have greater secondary task costs than younger adults during DA, indicating that they require more attentional resources to maintain memory performance under DA conditions.

The left parahippocampus was similarly involved in the FA, but not DA, network in younger and older adults (see Figure 1). This was also found by Anderson et al. (2000), and since the exclusion of this region from the DA network in younger and older adults could not be explained in terms of memory performance, they interpreted this dampening of activity as a difficulty in encoding the retrieval stimulus under DA. Since we also found that the change in activity did not affect memory performance, we agree with this interpretation.

Behaviour-Related Networks in Younger and Older Adults

We found that, although younger and older adults responded similarly to general manipulations of DA (i.e. percentage memory interference experienced in each DA condition did not differ across age groups), the spatial patterns related to successful memory differed dramatically. We found a pattern of brain activity that related to successful memory performance during all three memory conditions in younger adults. In contrast, a pattern of activity was found to relate to memory performance in the FA and DA-word, but not the DA-digit, conditions in older adults (see Figure 5). This finding is unexpected, and may reflect a change in either the strategies used or the qualitative nature of the memories retrieved by older adults; but testing such interpretations is beyond the scope of the current data.

We wished to test whether the additional left prefrontal cortex activity reported in older adults during studies of retrieval reflects functional compensation (Cabeza, Anderson, Locantore & McIntosh, 2002; Gutchess et al., 2005) or the inefficient use of attentional resources or inhibitory processes (Logan et al., 2002). The compensatory hypothesis would be supported if left PFC activity was more strongly positively related to successful memory performance in older, than younger, adults, whereas the inhibitory deficit hypothesis expects that left PFC activity is unrelated to successful memory performance in both age groups. We found that a region in the left prefrontal cortex related positively to memory performance in older adults in the FA and DA-word conditions (see Figure 6). However, we also found that activity in many left prefrontal regions was also positively related to successful memory performance in younger adults. Thus, the findings do not strongly support either hypothesis.

The finding that precuneus activity was related to memory accuracy in younger adults is interesting in light of recent work that demonstrates that precuneus activity found during episodic memory retrieval is not simply a reflection of attentional processes (Shannon & Buckner, 2004). Roland and Guylas (1995) and Krauss et al. (1999) have suggested that activity in the posterior neocortex during memory retrieval may reflect the reactivation of stored engrams. In addition, previous studies have also found that increased activity in the posterior neocortex is related to retrieval success (Dobbins et al.,2003; Lundstrom, Ingvar & Petersson, 2005; Shannon & Buckner, 2004). With these findings in mind, we suggest that activity in this region reflects the successful re-activation of the content representations of the memory trace.

We also found that the spatial pattern predicting successful memory performance in older adults included a region of the right parahippocampus (see Figure 7). Other work has found that although older adults show reduced hippocampal activity at retrieval (Cabeza et al., 2004; Grady et al., 2005), they often show greater parahippocampal activity than younger adults (Bäckman et al., 1997; Cabeza et al., 2004; Grady et al., 2005). Our findings suggest that the increased reliance on this region with age may aid memory retrieval in older adults.

Functional Connectivity of the Hippocampus

We tested the hypothesis that material-specific interference disrupts the ability of the hippocampus to index the content of the memory trace. The functional analysis showed that during all three memory conditions, hippocampal activity was associated with a fronto-parietal-cingulate network of activity in the younger adults. This network, however, was only found to co-vary with successful memory performance during the FA and DA-digit, but not the DA-word, conditions (see Figure 8). This supports the hypothesis that during memory specific interference, the hippocampus is unable to engage in the proper processes that index the content of the memory trace.

A single precuneus region was found to co-vary with right hippocampal activity and successful memory performance in the DA-word condition (see Figure 9). As the precuneus is believed to be involved in the reactivation of stored engrams (Roland and Gulyas, 1995; Krauss et al., 1999), this further suggests that during material-specific interference, successful memory retrieval depends crucially on the ability to access the content of the memory trace.

In contrast, the functional connectivity analysis of the older adults showed no consistent pattern between memory conditions. This agrees with additional studies that have found the role of the hippocampus changes with age (Cabeza et al., 2004; Grady et al., 2005), and that this may be associated with a decline in the task-related specificity of memory networks with age (Tisserand et al., 2005). For example, Tisserand et al. (2005) found that while younger adults showed two distinct spatial patterns relating to memory performance during encoding and retrieval, older adults showed large amounts of spatial-overlap in the brain regions, including the hippocampus, predicting memory performance during both memory tasks. This suggests that older adults may be using a more global memory network that is less able to engage unique neural processes in response to different task demands. Since aging is associated with reductions in long-term potentiation (Barnes, 1994), afferent input (Foster et al., 1991), and neurons (Lippa et al., 1992) in the hippocampus, it may be that neuroanatomical changes in this, and other brain regions, with age lead to the creation of a single memory network recruited during various memory tasks, as the ability to recruit multiple different networks that uniquely relate to different memory tasks (i.e., different FA and DA conditions) diminishes.

Other work has begun to demonstrate that there may be a shift from a reliance on hippocampal to parahippocampal activity with age. Cabeza et al. (2004) and Grady et al. (2005) both found that younger adults produced more right hippocampal activity during a memory recognition task, whereas older adults produced more left parahippocampal activity. Daselaar et al. (2006) has additionally shown that while hippocampal activity was associated with recollective (or contextual) processing in younger adults, older adults relied more heavily on activity in a rhinal cortex region relating to familiarity-based processing. In conjunction with our finding that activity in the right parahippocampus was found to predict successful memory performance in older adults only, the functional connectivity analysis further demonstrate that there may be a change in the medial temporal lobe regions engaged during memory retrieval in younger and older adults.

Conclusions and Preface to the Second Study

We found that that memory performance was relatively unaffected by general manipulations of available attention during retrieval, and that recruitment of brain regions to support behaviour in this condition did not differ significantly from full attention. Older, compared to younger, adults, however, require additional attentional resources during DA conditions, as indexed by the additional recruitment of PFC regions. We also found that there are differences in the brain regions related to successful memory performance, in younger and older adults. Lastly, we found that during material-specific interference, the network normally used to support successful memory performance is disrupted. We suggest that this occurs due to competition for the brain regions used to re-activate memory traces.

The changes in brain activity found during different DA conditions and age may relate to changes in the phenomenological experience associated with the retrieval of the memory. According to dual process models, there are two ways in which information can be recognized, referred to as “Recollection” and “Familiarity” (Gardiner, 1988; Jacoby, 1991; Mandler, 1980). Recollection usually refers to the effortful retrieval of detailed (e.g., contextual) information about individual personal episodes, whereas familiarity is thought of as an unspecific sense of having previously encountered a given event. There is some evidence that the two processes can be differentiated at the level of the brain. Within the field of neuroimaging, previous work has found that although recollection and familiarity both involve activity in frontal and parietal regions, recollection involves additional activity in frontal, sensory, and medial temporal cortical regions of the brain (Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Henson, Rugg, Shallice, Josephs, &Dolan, 1999; Wheeler & Buckner, 2004). For example, Wheeler and Buckner (2004) found that during the retrieval of words that had been paired with pictures during study, only the words that were recollected activated a sensory cortical region relating to picture processing. In addition, Henson et al. (1999) found that different regions of the frontal lobe were engaged during recollection and familiarity-based retrieval. These studies suggest that the phenomenological experience associated with a memory depends on the neural processes engaged during its retrieval.

Even though general manipulations of attention during retrieval do not affect the behavioural performance of memory retrieval, we found that there were some differences in the network used to retrieve memories, mostly in frontal lobe regions. This finding may suggest that general manipulations of attention can affect memory performance by changing the robustness, or quality of what is retrievable, by changing whether a memory is truly ‘recollected’ or whether it is simply ‘familiar’ to the participant. For example, participants may no longer remember the details associated with the initial encoding experience when attention is divided during retrieval with the digit-based distracting task. Instead, participants may simply have a sense that an item is familiar, and use this information to guide the memory decisions. Similarly, the changes in retrieval networks associated with age may be related to a change in the quality of what is retrieved in this group. However, the present study does not allow us to test this hypothesis.

In addition, during material-specific manipulations of attention, we found that the network used to support memory performance was disrupted in younger adults. However, this does not mean that recollection and familiarity are equally disrupted during this condition. If recollection and familiarity are supported by different networks, then it may be that material-specific manipulations only interfere with one of these processes, and that the other process is able to proceed unimpeded via some other network. In addition, since we found that material-specific manipulations altered the medial temporal network in younger, but not older adults, the manner with which material-specific manipulations of attention differentially affect recollection and familiarity may differ in younger and older adults. To examine these hypotheses, we conducted the second set of experiments in Study 2 of this thesis. This second study investigates whether general and material-specific manipulations of attention produce different patterns of recollective and familiarity-based responses, and whether these effects interact with age.

Chapter 3
Study 2: Divided Attention and the Remember-Know Technique

3.1 Dual Process Theories of Memory, Aging, and the Divided Attention Technique

Dual-process models of recognition postulate two ways in which information can be recognized, referred to as "Recollection" and "Familiarity" (Gardiner, 1988; Jacoby, 1991; Mandler, 1980). Recollection is defined as the mental reinstatement of previous events. During recollection, unique details of a memory are recalled, which may include additional sensory information such as the sounds paired with an event, or the emotions experienced during the initial encoding of the item, scene, or event. The second type of processing, referred to as Familiarity, is a mental awareness that an event has been experienced in the past, but the memory is lacking the unique details or mental reinstatement of the event that accompanies recollection.

The difference between these two processes is easily demonstrated in everyday life by the example of meeting a person you recognize on the street. Sometimes we can specifically place where, or when in the past, we had met the person. This is a recollective process. In contrast, sometimes we gain a strong sense that we have met the person before, but cannot identify where or when we originally encountered the individual. The person is familiar to us, despite the fact that we cannot recollect unique details of the initial meeting event. This is a familiarity process.

The Remember-Know paradigm was developed in order to study recollective and familiarity-based memory processes (Tulving, 1983, 1985). During a recognition memory test, participants are asked to make a 'Remember' (R) response if they recollect specific information about the item from the study phase, a 'Know" (K) response if the item is familiar in the absence of a specific recollection of the study episode, or a 'New' (N) response if the item is not deemed to be from the study list. In general, R responses are believed to reflect recollective memory processes, whereas K responses align more with familiarity-based recognition processes (Yonelinas, 2001; Yonelinas & Jacoby, 1995).

Recollection is generally described as a more controlled, analytic, and attention-demanding process than familiarity (Jacoby, 1991; Kelley & Jacoby, 1998). For instance, shallower levels of processing (Gregg & Gardiner, 1994; Rajaram, 1993) and divided attention at study (Gardiner, Gregg, & Karayianni, 2006, Gardiner & Parkin, 1990; Yonelinas, 2001) decrease recollective-based responding, while leaving familiarity unaffected. In contrast, familiarity is often referred to as a more automatic process, and is often described as an increase in an item's processing fluency (Johnston, Dark & Jacoby, 1991; Kelley & Jacoby, 1998), or a quantitative memory strength (Yonelinas, 1994). For example, speeded responding studies suggest that familiarity processes are present earlier than recollective processes (Yonelinas & Jacoby, 1994, 1995), and changing the perceptual characteristics of word stimuli at test decrease familiarity-based processing while leaving recollection unaffected (Rajaram, 1993; Rajaram & Geraci, 2000).

In order to further characterize the attentional requirements for recollection and familiarity-based recognition, we examined how performance on a Remember-Know memory test is affected, in younger and older adults, by manipulations of attention. While previous work has considered the role of attention during encoding, no study to date has examined how divided attention at retrieval affects recollection and familiarity in a Remember-Know paradigm.

<u>Recollection, Familiarity, and Reduced Attentional Resources in Age</u>

Knowledge about the role of attention in recollective and familiarity-based recognition can be gleaned from work with older adults, as psychologists often characterize the aging processes as a loss of available general attentional resources with advancing age, (Baddeley & Wilson, 1988; Craik, 1983; Craik & Byrd, 1982; Fuster, 1997; Knight & Grabowecky, & Scabini 1995; Luria, 1966; Rabinowitz, Craik & Ackerman, 1982; Shallice & Burgess, 1991), (see Section 1.2). Past work shows that older adults are less able to use recollective, or context-related, memory processes (Bastin & Van der Linden, 2003; Friedman & Trott, 2000; Java, 1996; Norman & Schacter, 1997; Schacter, Koustaal, & Johnson, 1997), whereas familiarity shows either no, or a less pronounced, decrease with advancing age (Friedman & Trott, 2000; Mark & Rugg, 1998; Norman & Schacter, 1997; Parkin & Walker, 1992; Java, 1996, Perfect, Williams, & Anderton-Brown, 1995; Perfect & Dasgupta, 1997; Schacter, Koustaal, & Johnson, 1997). As recollection is believed to be a more attention-demanding process than familiarity, the decline in recollection noted with advancing age may be related to this population's reduced levels of efficient processing on attention-demanding tasks (Java, 1996; Parkin & Walker, 1992; Davidson & Glisky, 2002).

The age-related reduction in recollective processing has been partly ascribed to an inability in older adults to properly encode the context of an event due to inefficient use of attentional resources (Benjamin & Craik, 2001; Caldwell & Mason, 2001; Davidson & Glitsky, 2002; Schacter, Koustaal, & Johnson, 1997). In line with this claim, performance of younger adults under divided attention (DA) conditions, during the encoding of information, mimics that of older adults under FA conditions: recollection, but not familiarity, estimates are reduced (Gardiner & Parkin, 1990; Mangels, Picton & Craik, 2001; Yonelinas, 2001). Other studies show that older adults may find it more difficult to properly engage the cognitive processes that integrate multiple features of an event at encoding (Chalfonte & Johnson, 1996; Glitsky, Rubin & Davidson, 2001; Naveh-Benjamin & Craik, 1995), leading to poorer recollection compared to younger adults. Finally, age-related decreases in recollection are minimized when encoding strategies are controlled (Perfect, Williams, & Anderton-Brown, 1995; Perfect & Dasgupta, 1997).

It is less well known whether attentional resources are also required to retrieve recollective-based memories. It is possible that the retrieval of contextual information associated with an event may require additional cognitive processing related to the search and/or monitoring of information (Davidson & Glitsky, 2002). Neuroimaging and ERP studies show that recollection of context, or source memory, as compared to familiarity or item-based memory retrieval, is related to an increase in prefrontal cortex (PFC) activity (Cansino, Maquet, Dolan, & Rugg, 2002; Duarte, Ranganath, Winward, Hayward, &Knight, 2004; Henson et al., 1999; Lepage, Brodeur & Bourgouin, 2003; Van Petten, Senkfor & Newburg, 2000; Wheeler & Buckner, 2004), and that older adults have different neural activation patterns in the PFC during source memory retrieval (Cabeza, Anderson, Lacontore, & McIntosh, 2002; Dywan, Segalowitz & Arsenault, 2002; Trott, Friedman, Ritter, Fabiani, 1997). This suggests that recollective-based memory retrieval may require more frontal lobe mediated processes than familiarity, and that a reduction in availability of these resources with age may lead to an inability to properly retrieve contextual information.

In contrast to the widely recognized decline in recollection associated with age, it is less clear as to whether there is an additional decline in familiarity. Studies have generally found either a small age-related decrease in familiarity (Mark & Rugg, 1998; Norman & Schacter, 1997; Perfect & Dasgupta, 1997; Schacter, Koustaal, & Johnson, 1997), or no change in familiarity with age (Friedman & Trott, 2000; Java, 1996; Parkin & Walker, 1992). Regardless, any possible age-related impairment in familiarity is not generally ascribed to deficits in attentional processing mediated by the PFC, but instead, due to possible changes in the integrity of medial temporal lobe structures (Davidson & Glitsky, 2002).

In summary, the aging research suggests that the retrieval process involved in recollection and familiarity differ in the amount of cognitive resources required, and that this influences how they are affected by age. It may thus be expected that a reduction of general attentional resources brought on by DA will disrupt recollection, but leave familiarity relatively unaffected, and that this disruption in recollection will be even greater in older adults. Currently, two studies have examined how DA at retrieval affects recollection and familiarity in younger adults, using the process-dissociation technique (Dodson & Johnson, 1996; Gruppuso, Lindsey & Kelley, 1997). While both studies found that recollection is affected more by DA at retrieval than is familiarity, each examined how attention interacted with additional variables (proportion of old targets and word frequency), making it difficult to make precise conclusions about the attentional demands of recollection and familiarity at retrieval.

In addition, a recent study by Gardiner and colleagues (2006) considered how conscious awareness or available resources at encoding and retrieval affected recollection and familiarity. They examined how Remember and Know responses were influenced by perceptual effects of study-test congruence when attention was divided during encoding, and whether such effects were influenced by a speeded responding manipulation (intended to reduce available conscious resources) during retrieval. They found that the perceptual effects in remembering and knowing depend more on available conscious resources at encoding than retrieval.

This finding challenges the assumption that recollection requires attentional resources at retrieval, an assumption integrated into many dual process theories. This finding also has implications for the aging data, in that it suggests that the age-related decrease in recollective processing is due solely to deficits in engaging attentional processes during encoding, and not retrieval. However, while speeded responding (as in Gardiner et al., 2006) reduces the amount of time one can devote to a task, this may affect attentional resource use in a qualitatively different way than in divided attention paradigms. For example, having full resources available for 2 seconds to perform a task may be different than having half of one's attentional resources available for 4 seconds. In the currently study we chose to examine how reduced levels of attentional resources, brought on by a division of attention, affect recollection and familiarity in a Remember-Know paradigm, and in addition, examined how these effects interact with age.

Divided Attention and the Resource Demands of Recollection and Familiarity

We may additionally consider work that uses DA at retrieval for clues as to the resource demands of recollection and familiarity during retrieval. Studies that have used DA during tests of memory that do not directly measure recollection and familiarity show minimal effects of attentional manipulations at retrieval on memory performance in both younger and older adults (Baddley et al., 1984; Craik et al., 1996; Macht & Buschke, 1983; Murdock, 1965; Naveh-Benjamin et al., 1998; Naveh-Benjamin et al., 2000; Naveh-Benjamin et al., 2000b; Nyberg et al., 1997; Park et al., 1989; Veiel & Storandt, 2003; Whiting & Smith, 1997), (see section 1.3). However, there are some exceptions to this finding. These exceptions may shed light on the components of retrieval that can be affected by DA conditions during retrieval.

The first exception is when the memory test requires organizational or source memory judgments. For example, large deficits in memory performance are observed during DA when the memory test requires recall from categorized word lists (Moscovitch, 1994; Park, Smith, Dudley & Lafronza, 1989), list discriminations (Jacoby, 1991), or involves release from proactive inhibition (Moscovitch, 1989, 1994). These studies indicate that when the memory test demands organization or re-creation of the contextual information tied to item memory, DA at retrieval leads to large and significant memory interference.

The second exception is when the memory and distracting task use similar material. Fernandes and Moscovitch (2000, 2002, 2003) found that recall of lists of unrelated words is disrupted when participants concurrently perform a word-based distracting task, but not when they perform a digit- or picture-based distracting task. They suggest that the locus of memory interference in their studies lies in reactivation of content representations of the item memory, rather than competition for general attentional resources. Furthermore, they showed that the magnitude of memory disruption, from a word-based distracter, in older adults was similar to that observed in younger adults (Fernandes & Moscovitch, 2003; Fernandes et al., 2004; Fernandes, et al., 2006), suggesting that the processes required to retrieve the content representation of a memory are intact in older adults (see Section 1.3).

In the present study, we tested whether this material-specific interference effect would act selectively on familiarity-based processing. It has been suggested that familiarity involves responding to the overall similarity of an item across study and test conditions, in a global matching process (Gillund & Shiffrin, 1984; Hintzman & Curran, 1994). In line with this suggestion, other work has shown that knowing, but not remembering, is more sensitive to variables that affect the perceptual and/or conceptual processing fluency of items. For example, Rajaram (1993) showed that presentation of a test word, preceded by an identical masked test prime, affected knowing and not remembering, and Dewhurst & Hitch (1997) showed that performing an auditory lexical decision task followed by an auditory test of recognition memory had a detrimental effect on accuracy of knowing, when lures in the recognition task were created from the non-words in the preceding lexical decision task. These studies suggest that knowing is particularly sensitive to manipulations that interfere with the re-creation of the representational content of memory.

According to Fernandes & Moscovitch (2000, 2002), large memory interference effects from DA at retrieval are observed only when there is competition for a common representational system in the dual tasks. Thus, the locus of memory interference at retrieval in their work lies in competition for content-specific representations in memory, needed during recall of words and when the distracting task also involves words. This suggested to us that manipulations of attention at retrieval should affect familiarity processes only when the distracter task uses similar material as the memory task, and the magnitude of this effect should be similar in younger and older adults.

Specific Hypotheses of the Present Study

In order to assess the attentional requirements of recollection and familiarity-based recognition, both Experiment 1 and Experiment 2 examined how performance on a Remember-Know memory test is affected, in younger and older adults, by division of attention during retrieval using either a digit or word-based distracter task. Experiment 2 was designed to address whether a digit-based distracter task of increased difficulty would show similar effects as when a material-specific (word-based), distracter task is used. Thus, Experiment 1 and Experiment 2 differ only in the digit-based distracter task, with Experiment 2 employing a more complex numerical task than Experiment 1. This ensures that the results of the study are due to the nature of the material in the distracter task, rather than difficulty level of the distracter task. In line with previous work (Fernandes et al., 2005), we expected overall recognition performance to be disrupted when retrieval is performed concurrently with a word based distracting task (DA-word) but not with a digit-based distracting task (DA-digit), and that the magnitude of this disruption will be similar in younger and older adults (Fernandes et al., 2006). Also, in line with previous work (Anderson et al., 1998; Naveh-Benjamin et al., 1998), we expected that costs to distracter task performance, during both DA conditions, would be greater in older, as compared to younger adults.

More important to the current study, we test the hypothesis that recollection requires frontal lobe-mediated attentional resources. To the extent that recollection requires such resources, Remember (R) responses should be reduced during either of our DA conditions, as both distracting tasks would reduce attentional resources available for R responses. We refer to this as a general effect of DA on recollection. In addition, since older adults have fewer available attentional resources than younger adults, this disruption should be greater in older adults as their limited resources are further reduced by the DA conditions.

In the present study, we additionally test the hypothesis that familiarity would be particularly disrupted in the DA-word condition, as the word-based distracting task would interfere with re-creation of the representational content of memory, critical to the familiarity process. We refer to this as a material-specific effect of DA on familiarity. Also, since representational aspects of cognitive function are believed to be preserved with aging, the magnitude of disruption to familiarity should be similar in younger and older adults.

3.2 Experiment 1: Methods, Results, and Discussion

3.2.1 Methods

Participants.

60 people took part in our study. 30 healthy undergraduate students from the University of Waterloo received course credit and 30 older adults recruited from the Waterloo Research Aging Pool (WRAP) at the University of Waterloo received token monetary remuneration for participating in the study. The WRAP pool is a database of healthy seniors in the Kitchener-Waterloo area recruited by means of newspaper ads, flyers in community centers, and through local television segments featuring research at the University. The mean age was 19.53 (SD = 1.57) for the younger adults and 74.53 (SD = 5.48) for the older adults. All participants learned to speak English by 7 years of age, and had normal or corrected-to-normal hearing and vision. The mean number of years of education for the younger adults was 14.03 (SD = 1.65) and for the older adults was 15.07 (SD = 1.84), which differed significantly, $t(58) = -2.29$, $p < .05$. The National Adult Reading Test – Revised (NART-R) was also administered to allow an estimate of Full Scale IQ (FSIQ), based on vocabulary reading. FSIQ is calculated based on the number of errors in pronunciation (Nelson, 1982; Blair & Spreen, 1989). Younger and older adults had mean FSIQ estimates of 113.06 (SD = 3.76) and 115.58 (SD = 6.14) respectively,

which did not differ significantly, t (58) = -1.92, $p > .05$. These estimates are comparable to the means reported by Graf and Uttl (1995) for younger (M = 117.41, SD = 6.70) and older adults (M =123.45, SD = 8.43). The Trail-Making test was also administered to establish an estimate of executive functioning (Reitan & Wolfson, 1985). The mean time to complete the Trails A (in seconds) for younger adults was 17.32 (SD = 3.25) and for older adults was 32.10 (SD = 15.72), which differed significantly, t (58) = -5.04, $p < .001$, and time to complete Trails B for younger adults was 36.23 (SD = 15.72) and for older adults was 67.15 (SD = 24.21), which also differed significantly, t (58) = -6.55, $p < .001$. These scores are within the range of the norms developed by Yuedell, Reddon, Gill, Stefanyk, (1987), with normalized means of 27.4 (SD = 9.6) and 58.7 (SD = 15.9) for younger adults, and 35.8 (SD = 11.9) and 81.2 (SD = 38.5) for older adults, for Trails A and B respectively. In addition, older adults were administered the Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975) to screen for gross neurological conditions. All had MMSE scores of greater than 26/30 (M = 29.07, SD = .98), indicating they were free from major cognitive and neurological impairments.

Materials.

Memory task.

All word stimuli for the recognition memory and animacy tasks were medium to high frequency words chosen from Celex, a lexical database available on CD-ROM (Baayen, Piepenbrock & Gulikers, 1995). Words in the study list, and lures for the subsequent recognition memory test, were spoken by author MF in a sound proof booth and recorded into a .wav file using SoundDesigner II software (Palo Alto, California).

For the memory task, three study lists were created by randomly choosing 50 words for each list, from a pool of 470 unrelated common nouns. Recognition test lists were then created by randomly choosing 30 words from the study list and an additional 20 words (to serve as lures) from the pool, to produce a 50 word recognition test. The recognition test was comprised of more old than new words so that we would get a greater number of Remember and Know responses for statistical testing. The three study and corresponding test lists were equated on letter length, utterance length, and word frequency, and were counter-balanced across conditions and participants. Each study list was presented auditorily via computer speakers at a rate of one item every two seconds, and the volume of word presentation was adjusted during the practice phase of the experiment so that all participants could hear the words clearly without straining their hearing. An additional 40 words were chosen for the practice phase of the experiment

Distracting tasks.

Items in the distracting tasks were presented visually (black on a white background) in Courier New font with font size 26. For the word task, a 50 and 100-word list was created for the single-word and DA-word conditions respectively (see Procedure). Lists consisted of words with a mean of six letters, representing living (e.g., kitten) and man-made (e.g. pencil) objects. Another 50-word list was created for use in the auditory continuous reaction time (CRT task described in procedure). The three word lists were equated on letter length and word frequency, and each list was created to contain half living and half man-made objects. In addition, another 20-word list was used for the practice session.

For the digit task, E-prime software was used to randomly generate 50 two-digit numbers during the single-digit condition and 100 two-digit numbers for the DA-digit condition (see Procedure). Each two-digit number was presented flanked by two X's on either side (e.g., XX47XX), so that the visual display consisted of 6 items, as in the word-based distracting task which consisted of words that were an average of 6-letters in length, with half of the items being odd digits. An additional 50- and 20-item list was created using a random number generator for use during the CRT task (see procedure), and practice session, respectively.

Procedure.

Stimulus presentation and response recording were controlled by an IBM PC, using E-prime v.1.1 software (Psychology Software Tools Inc., Pittsburg, PA). Participants were tested individually, and completed the experiment in approximately one hour. All participants began the experiment by performing the NART-revised and Trail Making Test, and older adults were also administered the MMSE. Participants were then given a short practice block (10-20 items per condition) for the S-digit, S-word, FA, DA-digit, and DA-word conditions. Following practice, the participants performed the five task conditions, with the condition presentation order counter-balanced across participants according to a Latin-square design.

For the single-digit task, participants were instructed to press the space bar with their dominant writing hand every time the digits represented an odd number. For the single-word task, participants were instructed to press the space bar every time the word on the screen represented a ‘man-made’ object. For both distracter tasks, items were presented at a rate of one item every 2s for the younger adults, and one item every 2.5s for the older adults.

During the study phase for each memory condition (FA, DA-digit, DA-word), participants were told to listen to a list of words and to try to memorize these for a later memory test, hence encoding was always performed with full attention. Words were presented at a rate of one item every two seconds for both younger and older adults. The encoding phase was followed by an arithmetic task, in which participants counted backwards by threes from a number presented visually on the computer screen for 30 seconds, in order to eliminate recency effects (as in Craik et al., 1996). During the retrieval phase, participants heard words auditorily, and were asked to make one of three verbal responses: 1) say “R” for words they were certain they heard in the study phase and could recollect specific associations to the study event, 2) say “K” when they were certain the word was from the study list but could not recollect any specific associations to the study event, or 3) say “N” for words they believed were not from the study list. Responses were recorded manually by the experimenter.

In the full attention (FA) retrieval condition, no distracting task was performed with recognition. In the divided attention digit (DA-digit) and divided attention word (DA-word) conditions, participants performed the recognition memory test concurrently with either the digit or word-based task. Thus, participants had to make an “R”, “K”, or “N” response aloud while also pressing the space bar to identify odd-digits or man-made objects, depending on the distracting task. Participants were told to divide their efforts equally between the two tasks.

Younger adults were given 4 seconds and older adults 5 seconds to make a response to each word in the recognition test, and the responses were recorded manually by the experimenter. For each word presented auditorily, two distracting task items were presented, with onset of the first distracting task item simultaneous with that for the auditorily presented item. Thus, participants were required to make two digit or animacy decisions for every memory response. The importance of placing 50% of their effort on the recognition task and 50% of their effort on the distracting task was emphasized. Participants were encouraged to respond as quickly and accurately as possible. Accuracy and reaction times were recorded by the computer for both distracting tasks.

Since age-related slowing of processing speed might affect participant's ability to respond to the memory and distracting tasks, we adjusted the presentation rates for the auditory recognition and distracting task in younger and older adults based on pilot testing in 3 younger and 4 older adults. Pilot data from two older and three younger subjects showed that when participants were required to make a recognition decision to words heard every 4s, and distracting task items every 2s, overall recognition accuracy under FA conditions was 42% in older adults, as compared to 60% in the younger adults. We tested an additional two older adults as pilot subjects who heard a word every 5s, and distracting task items presented every 2.5s, and found that accuracy in the FA condition increased to 57%, roughly equivalent to the younger adults. Thus, the 5s presentation rate for the recognition task was chosen for the older adults, and the 4s rate for younger.

<u>Comparing Difficulty of the Distracting Tasks.</u>

If the digit and word distracting tasks differ with respect to resource requirements, this could contribute to any differences observed in memory interference, from each DA condition. In order to compare resource demands, each distracter task was performed concurrently with an auditory continuous reaction time task (CRT). For the CRT task, participants were instructed to identify computer-generated tones as either low, medium, or high by pressing the appropriate key with the index, middle, and ring finger of the dominant hand. The tones were presented in random order, with a new tone presented after the participant made a key press or after three seconds had elapsed. Participants were instructed to respond as quickly and as accurately as possible. Participants performed the CRT task alone (single task condition) or in combination with the digit or word task (dual task conditions) for 100 s with distracting task items appearing every 2 s. This procedure was done only in the young adult sample, as seniors had extreme difficulty discriminating tones due to normal sensory loss with increasing age (Ostroff, McDonald, Schneider & Alain, 2003).

Participants first performed a practice block that ended once they could correctly identify tones on five consecutive trials. Participants then performed the single task condition. This was followed by the two dual task conditions, with half of the participants performing the dual digit CRT condition and half performing the dual word CRT condition first. In order to avoid having participants make two manual responses in the dual task conditions (one for the CRT task and another for the distracting task), participants made verbal responses for the distracting tasks that were recorded by the experimenter using a separate keyboard. The reaction time (RT) and number of correct responses on the auditory CRT task were recorded and analyzed as a means of gauging how demanding each distracting task was, with longer RTs indicating greater resource demands.

3.2.2 Results

Memory Task Performance.

We first examined memory performance with the Remember and Know responses combined to yield a measure of overall recognition accuracy in each condition. We then performed separate analyses on Remember and Know responses.

Overall Recognition.

We calculated the mean hit rate (out of 30), false alarms rate (out of 20), recognition accuracy (hit rate – false alarm rate) and d’. Because analyses showed the same pattern of results for all measures, only the statistics for recognition accuracy are reported.

Data were analyzed in a 3 (Attention) x 2 (Age group) x 5 (Task order) analysis of variance (ANOVA), with the first variable being within participants and the other variables being between participant manipulations.

Main effects and interactions of task order on performance were all non-significant. There was a main effect of Age group, F (1, 50) = 6.80, MSE = .03, p < .05, with older adults recognizing fewer words than younger adults, and a main effect of Attention, F (2, 100) = 30.25, MSE = .01, p < .001 (see Figure 1). Simple effects analyses showed that the mean recognition accuracy for the DA-word condition was significantly lower than the FA condition, F (1, 50) = 51.54, MSE = .03, p < .001, and the DA-digit condition, F (1, 50) = 32.18, MSE = .03, p < .001, and that the FA and DA-digit conditions did not differ from each other, F (1, 50) = 2.43, MSE = .02, p > .05 (see Figure 1). In addition, there was no Attention x Age group interaction, indicating that that the younger and older adults were similarly affected by the DA conditions.

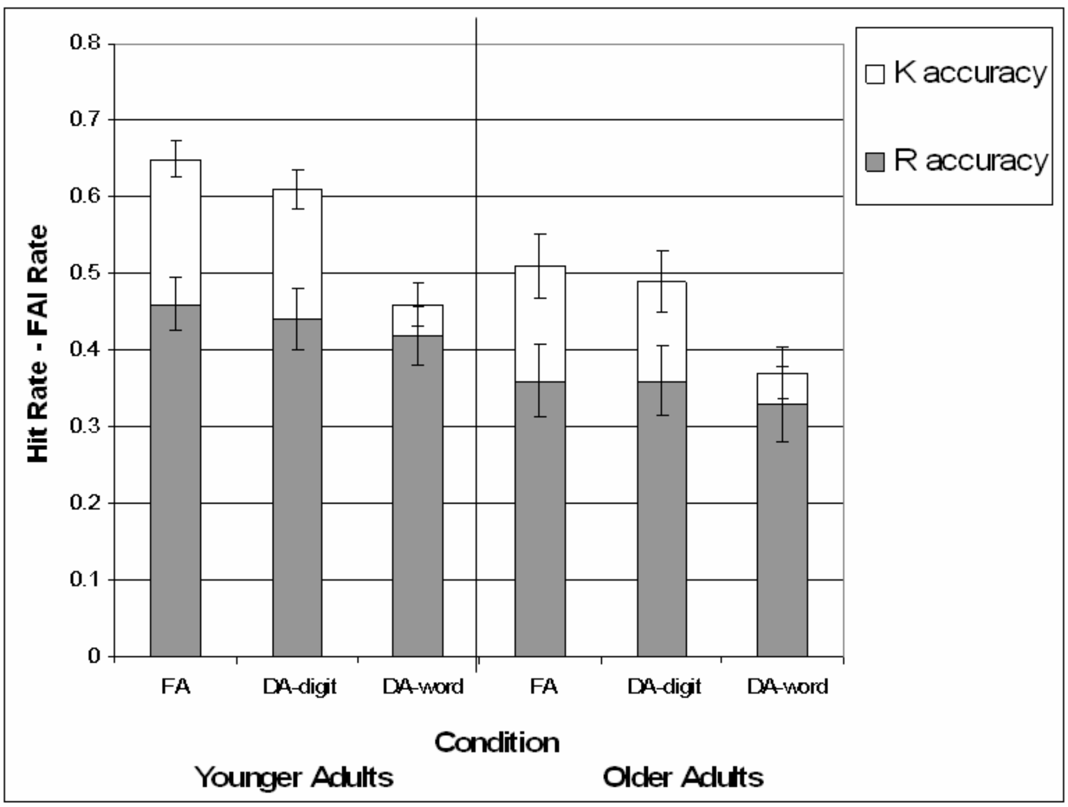

Fig. 10. Mean recognition accuracy under full attention (FA), divided attention digits (DA-digit) and divided attention word (DA-word) in younger and older adults. Grey bars show R accuracy and white bars show K accuracy rates. Error bars show the standard error of the mean. R = Remember, K = Know, and FA = False Alarm

We also examined the percentage decline in memory performance in the DA conditions, by subtracting the DA recognition accuracy from FA accuracy, and then dividing by FA accuracy and multiplying by 100. In this way we could examine directly the interference effects from DA, relative to each participant's own FA level of recall. The mean decline (hereafter referred to as memory interference) was -0.80 (SD = 35.66) and 3.2 (SD = 45.98) for the DA-digit condition, and 26.20 (SD = 38.63) and 28.77 (SD = 51.10) for the DA-word condition, for younger and older adults respectively. These data were analyzed in a 2 (DA condition) x 2 (Age group) x 5 (Task order) ANOVA. There was a main effect of DA condition, with greater interference in the DA-word than the DA-digit condition, F (1, 58) = 24.79, MSE = .01, $p < .001$. The Age group x DA condition interaction was non-significant.

Remember Responses.

We calculated the mean 'Remember' (R) hit rate (number of R responses given for old words divided by 30), R false alarms rate (number of R responses given to new words divided by 20), Recollection accuracy (R hit rate – R false alarm rate) and R d' (see Table 4). Although there is some controversy over whether memory measures based on signal detection theory, such a d', can be properly applied to studies that use the Remember-Know paradigm (see Donaldson, 2004, Gardiner, Ramponi & Richardson-Kloavehn, 2002), we included such analyses for the sake of completeness. These analyses did not change the pattern of results based on R and K responses significantly.

Table 4
Means and Standard Deviations of Remember and Know Measures for Younger and Older Adults.

Measure	Response	Full Attention		Divided Attention Digit		Divided Attention Word	
		Younger	Older	Younger	Older	Younger	Older
Hit Rate	Remember	.49 (.18)	.45 (.28)	.49 (.22)	.52 (.29)	.49 (.21)	.47 (.31)
	Know	.30 (.12)	.29 (.26)	.28 (.14)	.23 (.24)	.21 (.13)	.19 (.26)
False Alarm Rate	Remember	.027 (.06)	.089 (.10)	.043 (.08)	.155 (.14)	.062 (.11)	.14 (.15)
	Know	.11 (.08)	.14 (.17)	.11 (.09)	.10 (.11)	.17 (.12)	.16 (.26)
Accuracy (Hit Rate - False Alarm Rate)	Remember	.46 (.19)	.36 (.26)	.44 (.22)	.36 (.25)	.42 (.21)	.33 (.27)
	Know	.19 (.13)	.15 (.23)	.17 (.14)	.13 (.22)	.04 (.15)	.04 (.19)
d'	Remember	1.76 (.56)	1.23 (.88)	1.65 (.71)	1.08 (.85)	1.61 (.65)	1.07 (.96)
	Know	.73 (.52)	.52 (.80)	.69 (.54)	.41 (.75)	.16 (.62)	.02 (.73)
Independence Model Measures	Remember	.46 (.19)	.36 (.26)	.44 (.22)	.36 (.25)	.42 (.21)	.33 (.27)
	Know	.34 (.23)	.17 (.34)	.28 (.24)	.14 (.28)	.03 (.25)	-.08 (.63)

Response and Condition

Separate ANOVAs were conducted for each dependent measure, in a 3 (Attention) x 2 (Age group) x 5 (Task order) ANOVA. Analysis of the R false alarms showed a main effect of Age group, with older adults producing more R false alarms than younger adults, F (1, 50) = 12.34, MSE = .01, $p < .005$ (see Figure 11). We also found a main effect of Attention, F (2, 100) = 5.27, MSE = 0.01, $p < .01$. Simple effects tests showed that there were significantly more false alarms made in the DA-digit, F (1, 50) = 9.34, MSE = .01, $p < .005$, and in the DA-word condition, F (1, 50) = 7.88, MSE = .02, $p < .01$, compared to the FA condition, but that false alarms in the DA-digit and DA-word conditions did not differ from each other, F (1, 50) = .02, $p > .05$ (see Figure 11). The Attention x Age group interaction did not reach significance, F (2, 50) = 1.37, p = 2.59. In order to increase the sensitivity of detecting the interaction between attention and age group, we averaged the probability of producing a false alarm in the DA-digit and DA-word conditions, and compared this to FA conditions. The Attention x Age group interaction was not significant, F (1, 58) = 2.56, p = .156, but planned comparisons showed that the trend was in the direction of older adults showing higher false alarm rates than young during DA as compared to the FA conditions, t (58) = 3.48, $p < .005$, t (58) = 2.88, $p < .01$, respectively.

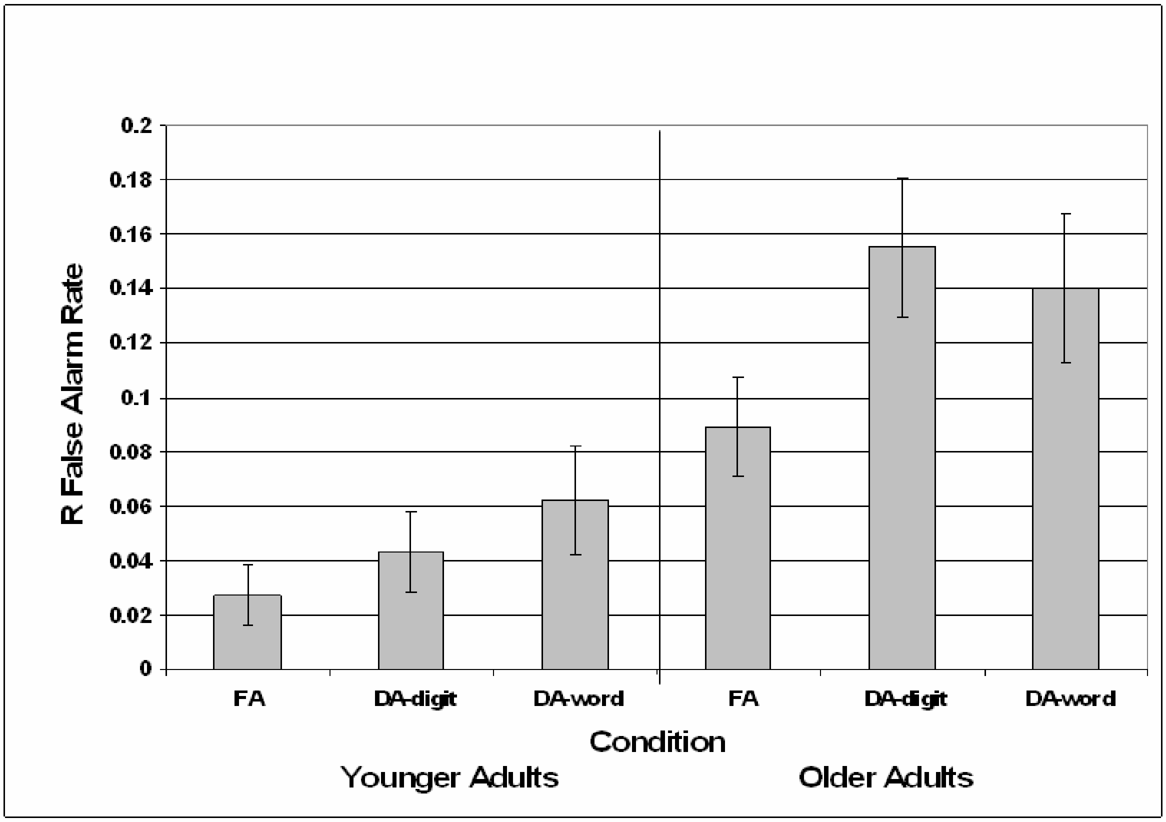

Fig. 11. Mean false alarm rate for 'Remember' responses under full attention (FA), divided attention digits (DA-digit) and divided attention word (DA-word) in younger and older adults. Error bars show the standard error of the mean.

We found a marginal main effect of Age group on recollection accuracy, F (1, 50) = 2.92, MSE = .01, p = .09, and a main effect of Age group on R d', F (1, 50) = .46, MSE = .12, $p < .01$, with younger adults showing higher estimates than older adults on both measures (see Table 4). There were no other significant main effects or interactions.

Know Responses.

We calculated the mean 'Know" (K) hit rate (the number of K responses given for old words divided by 30), K false alarms rate (the number of K responses that were to new words divided by 20), Knowing accuracy

(K hit rate – K false alarm rate), K d', as well as an independence measure of familiarity (K hit rate – K false alarm rate / 1 – (R hit rate – R false alarm rate), (Yonelinas & Jacoby, 1995), (see Table 4). Separate ANOVAs were conducted for each dependent measure, in a 3 (Attention) x 2 (Age group) x 5 (Task order) ANOVA.

The K hit rate ANOVA revealed no main effect of Age group, but a main effect of Attention, F (2, 100) = 14.90, MSE = .01, $p < .001$ (see Table 4). Importantly, simple effects tests showed that the there was a greater K hit rate in the FA than in the DA-digit, F (1, 50) = 5.20, MSE = .02 $p < .05$, and DA-word condition, F (1, 50) = 29.47, MSE = .02, $p < .001$, and also that K hit rate was significantly higher in the DA-digit than DA-word condition, F (1, 50) = 10.57, MSE = .02, $p < .005$.

The ANOVA for K accuracy measures revealed no main effect of Age group, F (1, 50) = .57, $p > .05$, a main effect of Attention, F (2, 100) = 24.15, MSE = .01, $p < .001$, and importantly, no Age group X Attention interaction, F (2, 50) = .55, MSE = .01, $p > .05$ (see Figure 10). Again, simple effects analyses revealed that K accuracy was lower in the DA-word than FA condition, F (1, 50) = 37.70, MSE = .03, $p < .001$, and the DA-digit condition, F (1, 50) = 28.55, MSE = .02, $p < .001$. The FA and DA-digit conditions did not differ from one another, F (1, 50) = 1.37, $p > .05$. We found this same pattern of results for the K false alarm rate, K d', and independence model measures of familiarity, except that in this last dependent measure there was also a main effect of Age group, F (1, 50) = 6.39, MSE = .05, $p < .05$, with younger adults showing higher familiarity estimates (see Table 4) overall.

Distracter Task Performance.

Accuracy.

The means for accuracy (hit rate – false alarm rate) and reaction time (RT) for correct responses to the distracter tasks are presented in Table 5. The data were analyzed in a 2 (Distracter task) x 2 (Attention) x 2 (Age group) x 5 (Task order) ANOVA, with the first two variables being within participant and the last two variables being between participant manipulations. There was a main effect of Distracter task, F (1, 100) = 118.63, MSE = .01, p < .001, with poorer performance in the word than digit distracter task. There was also a main effect of Attention, F (1, 100) = 118.42, MSE = .01, p < .001, with performance higher in the single task than dual task conditions. We also found a Distracter task x Attention interaction, F (1, 100) = 57.37, MSE = .01, p < .001, and planned comparisons revealed that while there was a significant decrease in distracter task performance under divided attention conditions, the decrease was greater for the word task, t (118) = 10.60, p < .001, than the digit task, t (118) = 8.22, p < .001. The main effect of Age group was not significant, and there were no other 2-way, 3-way or 4-way interactions with these variables.

Table 5

Means and Standard Deviations of Distracter Task Accuracy, Percentage of Decline in Accuracy from Single-Task to Dual-Task Conditions, Distracter Task Reaction Time (in milliseconds), and Percentage of Increase from Single-Task to Dual-Task Conditions for Younger and Older Adults.

	Condition			
Measure	Single Digit	DA-Digit	Single Word	DA-Word
Accuracy	.96 (.04)	.90 (.08)	.93 (.07)	.72 (.16)
% Accuracy Decline	--	5.43 (10.62)	--	31.00 (18.10)
Reaction Time	618 (91)	756 (116)	733 (103)	1149 (151)
% Reaction Time Increase	--	16.80 (7.95)	--	20.37 (9.77)

We also examined the percent decline in distracter task accuracy, calculated by subtracting the dual task accuracy from the single task accuracy, and dividing this by single task accuracy and multiplying by 100 (see Table 5), to yield a value expressing the percentage decline in distracter task performance. We found a main effect of Distracter task, F (1, 50) = 113.18, MSE = 119.51, p < .001, indicating that there were greater costs to performance in the word task (M = 27.58) than in the digit task (M = 6.35). There was no main effect of Age group, and importantly, there was no Distracter task x Age group interaction, F (1, 50) = 1.57, p > .05, indicating that distracting task interference during the dual conditions was equivalent across age groups.

In order to examine possible trade-offs between memory and distracter task performance, we calculated the correlation between interference measures for younger and older adults for the divided attention conditions. Young adults did not show significant correlations for either the DA-digit, $r = .114$, $p > .05$, or DA-word conditions, $r = .239$, $p > .05$. In contrast, the older adults showed no significant correlation for the DA-digit condition, $r = .138$, $p > .05$, but a significant positive correlation for the DA-word condition, $r = .379$, $p < .05$, indicating that as memory interference increased, so did distracting task interference. None of the correlations were in a direction to suggest trade-offs between the memory and distracting task.

Reaction Time.

The mean RT for correct responses in the distracter tasks is presented in Table 5, for each condition. Data were once again analyzed in a 2 (Distracter task) x 2 (Attention) x 2 (Age group) x 5 (Task order) ANOVA. We found a main effect of Distracter task, F (1, 100) = 269.13, MSE = 6302.72, $p < .001$, with longer RTs in the word than digit task, a main effect of Age group, F (1, 100) = 64.99, MSE = 22977.02, $p < .001$, with longer RTs in older than younger adults, and a main effect of Attention, F (1, 100) = 113. 41, MSE = 6302.72, $p < .001$, with longer RTs in the dual than single-task conditions. There was a significant Distracter task x Age group interaction, F (1, 50) = 4.14, MSE = 6302.72, $p < .05$, such that age differences in reaction time were slightly larger in the word task, than in the digit task. There was also a significant Distracter task X Attention interaction, F (1, 100) = 7.94, MSE = 6302.72, $p < .01$, with the difference in RT between the FA and DA conditions being greater for the word than for the digit task. There was a significant Age group x Attention interaction, F (1, 100) = 5.95, MSE = 22977.02, $p < .05$, with the difference in RT between FA and DA being greater in the older than the younger adults, t (118) = -4.53, $p < .001$. Lastly, we found an Age group x Task order interaction, F (4, 100) = 3.48, MSE = 22977.02, $p < .05$. Younger adults showed significantly faster reaction times during task order 5 (received single distracter task last and dual first) as compared to task order 1 (received single distracter tasks first and dual last), t (46) =-2.38, $p < .05$, whereas the older adults did not, t (46) = 1.8, $p > .05$.

We also examined the percentage increase in RT, by subtracting single task RT from dual task RT, dividing by the dual task RT, and then multiplying the value by 100 (see Table 5). There was a main effect of Age Group, $F\ (1, 50) = 5.03$, $MSE = .02$, $p < .05$, with older adults showing longer RTs overall. There was no main effect of Distracter Task, $F\ (1, 50) = 1.08$, $MSE = .01$, $p > .05$. All other main effects and interactions were non-significant. Correlations between increase in RT and decline in memory performance for both age groups were all non-significant, indicating that it is unlikely there were trade-offs between memory and latency on the distracter tasks.

Distracting Task Performed Concurrently with the Auditory CRT Task.

In order to examine the resources necessary to perform the distracting tasks, we examined CRT task performance alone, and in combination with each of the distracting tasks, in our young adult sample. We also analyzed accuracy on each distracting task when performed concurrently with the CRT task.

Auditory CRT Data.

The mean RT to identify correct tones was analyzed using a 3 (Attention) x 2 (Task order) ANOVA. Mean RT for the single, dual digit and dual word conditions were 696 ($SD = 173$), 1028 ($SD = 264$), and 1065 ($SD = 252$) respectively. We found a main effect of Attention, $F\ (2, 27) = 134.14$, $MSE = 9250.04$, $p < .001$, with simple effects analyses showing faster reaction times in the single CRT condition than in the dual digit CRT, $F\ (1, 28) = 170.10$, $MSE = 19576.54$, $p < .001$, and the dual word CRT task, $F\ (1, 28) = 247.00$, $MSE = 16564.56$, $p < .001$. Importantly, RT in the dual digit CRT and dual word CRT conditions did not differ, $F\ (1, 28) = 2.11$, $p > .05$. There was also an Attention x Task order interaction, $F\ (2, 27) = 4.98$, $MSE = 197673.30$, $p < .05$. The mean RT for the dual digit CRT task was significantly faster in task order 1 (received dual word CRT task first) than task order 2, $t\ (28) = -2.47$, $p < .05$, but there were no task order effects for the single CRT or dual animacy CRT conditions.

The mean number of tones identified was analyzed using a 3 (Attention) x 2 (Task order) ANOVA, with the first variable being a within-participant and the second variable a between-participant manipulation. The mean number of correctly identified tones was 122 (SD = 55) for the single, 80 (SD = 38) for the dual digit, and 74 (SD = 35) for the dual word conditions. We found a main effect of Attention, $F(2, 27) = 90.25$, $MSE = 224.74$, $p < .001$. Simple effects analyses showed that the number of tones identified was higher in the single CRT condition than in the dual digit CRT, $F(1, 28) = 108.17$, $MSE = 487.66$, $p < .001$, and the dual word CRT conditions, $F(1, 28) = 92.86$, $MSE = 731.97$, $p < .001$. In addition, the number of tones identified was lower in the dual word task than the dual digit task, $F(1, 28) = 7.48$, $MSE = 128.78$, $p < .05$.

Distracting Task performed concurrently with CRT data.

Distracting task accuracy (hit rate – false alarm rate) was calculated and analyzed using a 2 (Distracting task) x 2 (Task order) ANOVA. Distracter task accuracy rate was .81 (SD = .11) in the dual digit condition and .77 (SD = .11) in the dual word condition. Analyses showed that the main effect of Distracting task was not significant, $F(1, 28) = 2.29$, $MSE = .01$, $p > .05$, indicating that distracting task accuracy was equivalent in the two dual task conditions.

3.2.3 Discussion

These data show that when attention is divided at retrieval, false Remember responses increase, regardless of the material used in the distracter task. In addition, we have also shown that familiarity-based retrieval is disrupted only when the distracter task contains material that is similar to the memory task, as accurate Know responses decreased only during the DA-word condition. The implications of these findings are discussed further in the general discussion.

In order to ensure that the decline in memory performance, specifically to K responses, during the DA-word condition is due to the material, and not resource requirements, of the distracter task, it is important to establish that the digit-based and word-based distracter tasks do not differ with respect to resource requirements. We found that both younger and older adults were less accurate, and had increased latency to respond, when identifying man-made objects than when identifying odd digits, during single and dual task conditions. However, during single task conditions, since both groups were potentially at ceiling, the differences in accuracy were likely due to the limited range in variance associated with the measure, and not task difficulty. In addition, during dual task conditions, if as we believe, performing the two word-based tasks at the same time produces a competition for content representations, we would expect that performance on the word-based task would decrease significantly during the DA-word condition, since individuals would have a harder time accessing animacy information about the word due competition for representational systems with the words in the memory task.

Importantly, although RTs were slower for the word-based than digit-based task, we did not find a difference in the percent increase in distracter task RT during the DA conditions. If the memory interference shown during the DA-word condition was due to a difference in task difficulty, we would expect a significantly greater increase in RT during the DA-word condition.

In addition to this, when younger adults performed the CRT task concurrently with each of the distracter tasks, distracter task accuracy did not differ, though we acknowledge the number of tones correctly identified on the CRT task was lower during the word-based, rather than the digit-based, dual task condition. Because accuracy is less sensitive to differences in task difficulty, we also considered RT to identify tones. RT did not differ across distracter tasks in either experiment, suggesting that they have equivalent levels of difficulty.

Finally, we found that the effect of each of the DA conditions on R responding did not differ for the DA-word and DA-digit tasks. If the former is a more difficult distracting task than the latter, then R responding should have been affected more by the DA-word than DA-digit condition, but it was not.

Thus, the data generally show that the digit and word-based distracter tasks were of similar difficulty. However, in order to address this concern, we replicated the experiment again in Experiment 2 using the same word-base distracting task as in Experiment 1, and substituting the digit-based one for a more difficult distracting task, that was also digit-based but more complex than the one used in Experiment 1. We tested another group of young adults, naïve to the experiment, and examined recollection and familiarity estimates under FA and these two DA conditions.

3.3 Experiment 2: Methods, Results, and Discussion

3.3.1 Methods

Participants.

30 healthy undergraduate students from the University of Waterloo received course credit or token monetary remuneration. All participants learned to speak English by 7 years of age, and had normal or corrected-to-normal hearing and vision. The mean age was 20.20 (SD = 2.19) and the mean number of years of education was 15.30 (SD = 2.04). The National Adult Reading Test – Revised (NART-R) was also administered to allow an estimate of Full Scale IQ (FSIQ), based on vocabulary reading. FSIQ is calculated based on the number of errors in pronunciation (Nelson, 1982; Blair & Spreen, 1989), which gave a mean FSIQ estimate of 108.52 (SD = 6.85). The Trail-Making test was also administered to establish an estimate of executive functioning (Reitan & Wolfson, 1985). The mean time to complete the Trails A (in seconds) was 19.50 (SD = 5.12), and time to complete Trails B was 33.42 (SD = 10.75), which is within the normal range (Spreen & Strauss, 1998).

Materials.

Memory Task.

Memory tasks were the same as in Experiment 1. The memory task thus began with the auditory presentation of 50 words, presented at a rate of one word every 2 seconds. This was then followed by a recognition task that contained 30 old and 20 new words, presented at a rate of one word every 4 seconds, for which participants made a ‘Remember’, ‘Know’, or ‘New’ judgment. The memory task was again performed either alone (Full Attention) or in combination with the digit-based (DA-digit) or word-based (DA-word) distracter task.

Distracting tasks.

The word-based distracter task was the same as Experiment 1, and required participants to identify 50 words as either man-made or living objects, with words visually presented at a rate of one word every two seconds. The digit-based distracter task had the same visual presentation as in Experiment 1, with two- digit numbers flanked by two X's on either side (e.g., XX47XX) presented at a rate of one item every two seconds. However, for this task participants were required to add the two digits together, and press the space bar with their dominant right hand if the two numbers added to a number greater than 10. As in Experiment 1, half of the digit combinations required a response. Distracter tasks were again performed either alone (single-digit and single-word conditions) or in combination with the memory task (DA-digit and DA-word conditions).

Procedure.

The procedure was essentially identical to Experiment 1. Thus, participants began the task by performing the NART and Trail-making Test, followed by a short practice session of all conditions. Participants then performed the single-digit, single-word, full attention (FA), divided attention digit (DA-digit), divided attention word (DA-word) conditions, with the order of presentation of the conditions counter-balanced across participants. However, in this study the single-digit and DA-digit condition required participants to perform the numerical addition digit task, rather than the digit identification task of Experiment 1. In addition, at the end of the study in Experiment 2, participants completed a questionnaire that asked them to describe their experiences during the study.

After the study was completed, participants were required to perform the auditory continuous reaction time (CRT) task either alone or in combination with the digit-based and word-based distracter task. This was again done to determine the resource requirements of the distracting tasks, with greater costs to CRT performance indicative of greater resource demands. As in Experiment 1, the CRT task required participants to identify tones as high, medium, or low, as quickly and accurately as possible. Both reaction time and accuracy were recorded. After a quick practice session, participants performed the CRT task alone (single task condition). Participants then performed the CRT task while concurrently performing the new digit-based and word-based distracting tasks (dual task conditions), with half of the participants receiving the digit-based dual task condition first. Distracting task performance was recorded by the experimenter on a separate keyboard.

3.3.2 Results

Memory Task Performance.

We again examined memory performance with the Remember and Know responses combined to yield a measure of overall recognition accuracy in each condition first. We then performed separate analyses on Remember and Know responses.

Overall Recognition.

We calculated the mean hit rate (out of 30), false alarm rate (out of 20), recognition accuracy (hit rate – false alarm rate) and d'. Because analyses showed the same pattern of results for all measures, only the statistics for recognition accuracy are reported.

Data were analyzed in a 3 (Attention) x 5 (Task order) analysis of variance (ANOVA), with the first variable a within participants and the second variable a between participants manipulation. The assumption of sphericity was not met, $W(2) = .78$, $p < .05$, so a Greenhouse-Geiser correction was applied to the degrees of freedom. There was a main effect of Attention, $F(2, 41) = 4.29$, $MSE = .04$, $p < .05$ (see Figure 12). Simple effects analyses showed that the mean recognition accuracy for the FA condition was higher than the DA-word condition, $F(1, 25) = 6.34$, $MSE = .07$, $p < .05$, but the FA and DA-digit conditions did not differ, $F(1, 25) = .66$, $p > .05$. The recognition accuracy was also marginally higher in the DA-digit than the DA-word condition, $F(1, 25) = 3.52$, $MSE = .08$, $p < .08$ (see Figure 12).

As before, we also examined the percentage decline in memory performance in the DA conditions, to examine directly the interference effects from DA, relative to each participant's own FA level of recall. The mean decline (hereafter referred to as memory interference) was 4.08 ($SD = 30.09$) for the DA-digit condition, and 17.82 (SD = 49.10) for the DA-word condition. These data were analyzed in a 2 (DA condition) level repeated measures ANOVA. We did not find a main effect of DA condition, $F(1, 25) = 2.10$, $p > .05$.

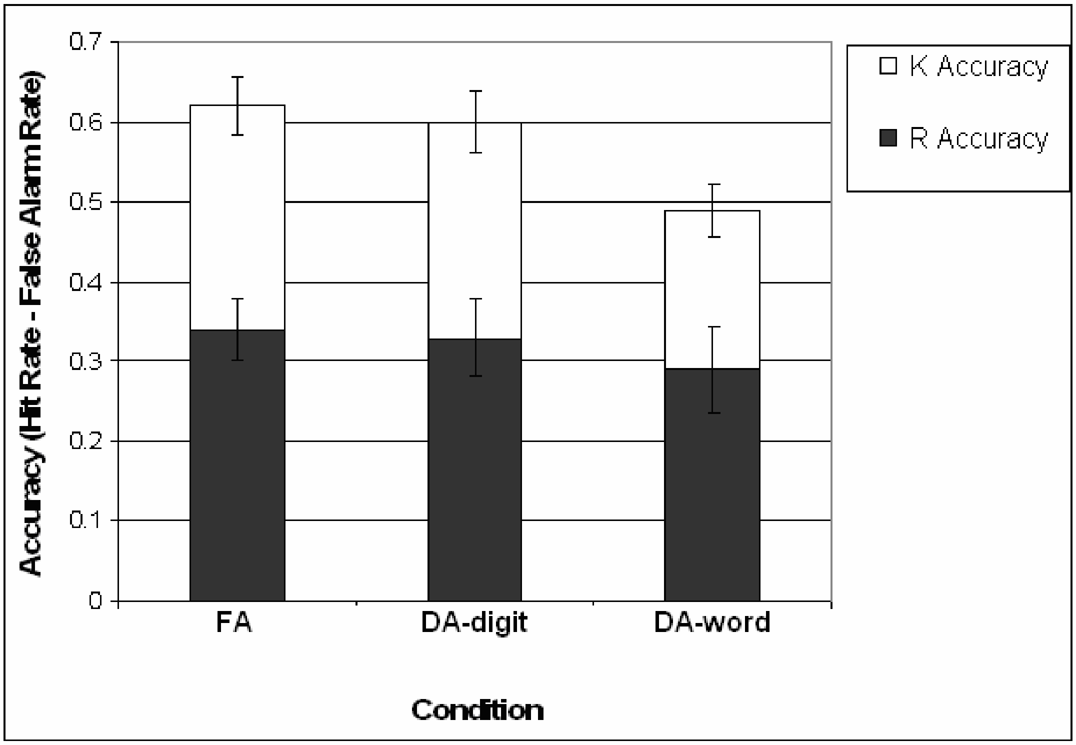

Figure 12. Mean recognition accuracy under full attention (FA), divided attention digits (DA-digit) and divided attention word (DA-word) conditions. Grey bars show R accuracy and white bars show K accuracy rates. Error bars show the standard error of the mean. R = Remember, K = Know.

Remember Responses.

We calculated the mean ‘Remember’ (R) hit rate (number of R responses given for old words divided by 30), R false alarms rate (number of R responses given to new words divided by 20), Recollection accuracy (R hit rate – R false alarm rate) and R d’ (see Table 6). Separate ANOVAs were conducted for each dependent measure, in a 3 (Attention) x 5 (Task order) ANOVA. Main effects and interactions of Task order on performance were all non-significant.

Table 6

Means and Standard Deviations of Remember and Know Measures.

Response	Response and Condition					
	Full Attention		Divided Attention Digit		Divided Attention Word	
Measure	Remember	Know	Remember	Know	Remember	Know
Hit Rate	.34 (.22)	.37 (.20)	.35 (.27)	.38 (.22)	.35 (.26)	.32 (.22)
False Alarm Rate	.00 (.01)	.08 (.10)	.02 (.03)	.12 (.11)	.06 (.14)	.11 (.09)
Accuracy (Hit Rate - False Alarm Rate)	.34 (.22)	.28 (.20)	.33 (.27)	.27 (.21)	.29 (.30)	.20 (.18)
d'	1.43 (.76)	1.11 (.73)	1.28 (.98)	.95 (.71)	1.17 (1.07)	.68 (.69)
Independence Model Measures	.34 (.22)	.41 (.27)	.33 (.27)	.41 (.28)	.29 (.30)	.26 (.28)

Analysis of the R false alarms showed a main effect of Attention, F (2, 50) = 3.64, MSE = 0.01, p < .05. Simple effects tests showed that there were fewer false alarms in the FA condition than in the DA-digit, F (1, 25) = 9.02, MSE = .00, p < .01, and in the DA-word condition, F (1, 25) = 5.03, MSE = .02, p < .05, but that false alarms in the DA-digit and DA-word conditions did not differ, F (1, 29) = 2.28, p > .05 (see Table 6). We also found a main effect of Attention on R d' F (2, 50) = 3.96, MSE = .13, p < .05. Simple effects tests showed that R d' was higher in the FA as compared to the DA-word condition, F (1, 25) = 6.27, MSE = .33, p < .05, and marginally higher in the FA as compared to the DA-digit condition, F (1, 25) = 3.35, MSE = .20, p < .08. The R d' in the DA-digit and DA-word conditions did not differ, F (1, 25) = 1.50, p > .05. There were no main effect of Attention on R hit rate, F (2, 50) = .17, p > .05 or Recollection accuracy, F (2, 50) = 1.61, p > .05.

Know Responses.

We calculated the mean 'Know" (K) hit rate (the number of K responses given for old words divided by 30), K false alarms rate (the number of K responses that were to new words divided by 20), Knowing accuracy (K hit rate – K false alarm rate), K d', as well as an independence measure of familiarity (K hit rate – K false alarm rate / 1 – (R hit rate – R false alarm rate), (see Table 6). Separate ANOVAs were conducted for each dependent measure, in a 3 (Attention) x 2 (Age group) x 5 (Task order) ANOVA.

The K hit rate data failed to meet the assumption of sphericity, W (2) = .61, p < .01, and so a Greenhouse-Geiser correction was applied. There was a marginally significant main effect of Attention, F (2, 36) = 2.72, MSE = .02, p < .1 (see Table 6). Simple effects tests showed that there was a marginally greater K hit rate in the DA-digit than in the DA-word condition, F (1, 25) = 3.71, MSE = .04 p < .07. There was no difference in K hit rate between the FA and DA-digit, F (1, 25) = .68, p > .05, or DA-word condition, F (1, 25) = 2.23, p > .05.

The ANOVA for K accuracy measures revealed a main effect of Attention, F (2, 50) = 3.17, MSE = .02, p = .05 (see Figure 12). Importantly, simple effects analyses showed that K accuracy was lower in the DA-word condition than the FA, F (1, 25) = 5.60, MSE = .04, p < .05, and also lower than the DA-digit condition, F (1, 25) = 2.78, MSE = .04, p = .1. The FA and DA-digit conditions did not differ from one another, F (1, 25) = .41, p > .05.

The ANOVA for independence measures of familiarity also showed a main effect of Attention, F (2, 50) = 5.19, MSE = .04, p > .01, with simple effects tests showing that familiarity was again lower in the DA-word than the FA, F (1, 25) = 9.27, MSE = .07, p < .01, and the DA-digit, F (1, 25) = 5.81, MSE = .12, p < .05, conditions. Familiarity measures did not differ between the FA and DA-digit conditions, F (1, 25) = .01, p > .05. Lastly, there was a main effect of K d', F (2, 50) = 4.74, MSE = .30, p < .05. As in the measures reported above, simple effects tests showed that while the K d' in the FA and DA-digit conditions did not differ from one another, F (1, 25) = 1.93, p > .05, the K d' was lower in the DA-word as compared to both the FA, F (1, 25) = 9.02, MSE = .62, p < .01, and DA-digit conditions, F (1, 25) = 3.07, MSE = .71, p < .1 (see Table 6). There was no effect on K false alarm rate (see Table 6).

Distracter Task Performance.

Accuracy.

The means for accuracy (hit rate – false alarm rate) and reaction time (RT) for correct responses to the distracter tasks are presented in Table 7. The data were analyzed in a 2 (Distracter task) x 2 (Attention) x 5 (Task order) ANOVA, with the first two variables being within participant and the last variable being a between participant manipulation. Main effects and interactions involving Task order were all non-significant. There was a main effect of Distracter task, $F(1, 25) = 33.89$, $MSE = .01$, $p < .001$, with higher accuracy in the digit than word distracter task. There was also a main effect of Attention, $F(1, 25) = 64.34$, $MSE = .01$, $p < .001$, with accuracy higher in the single task than dual task conditions. We also found a Distracter task x Attention interaction, $F(1, 25) = 21.47$, $MSE = .01$, $p < .001$, and planned comparisons showed that while there was not a significant difference in accuracy between the digit and word-based distracter tasks under single task condition, $t(29) = 2.98$, $p > .05$, accuracy was higher in the digit, as compared to the word, task under dual task conditions, $t(29) = 6.04$, $p < .001$.

Table 7

Means and Standard Deviations of Distracter Task Accuracy (hit rate – false alarm rate), Percentage of Decline in Accuracy from Single-Task to Dual-Task Conditions, Distracter Task Reaction Time (in milliseconds), and Percentage of Increase from Single-Task to Dual-Task Conditions. DA = Divided Attention.

	Condition			
Measure	Single Digit	DA-digit	Single Word	DA-word
Accuracy	.96 (.04)	.90 (.08)	.93 (.07)	.72 (.16)
% Accuracy Decline	--	6.17 (7.75)	--	22.08 (16.53)
Reaction Time	652 (107)	863 (116)	715 (94)	928 (105)
% Reaction Time Increase	--	24.22 (9.07)	--	22.46 (9.59)

We also examined the percent decline in distracter task accuracy, calculated by subtracting the dual task accuracy from the single task accuracy, and dividing this by single task accuracy, and multiplying by 100 (see Table 7), to yield a value expressing the percentage decline in distracter task performance. We found a main effect of Distracter task, F (1, 25) = 23.62, MSE = 160.78, $p < .001$, indicating that there were greater costs to performance in the word task than in the digit task (see Table 2).

In order to examine possible trade-offs between the memory task and distracting task performance, we calculated the correlation between interference measures in the divided attention conditions. There were no significant correlations for either the DA-digit, $r = -0.22$, $p > .05$, or DA-word conditions, $r = .04$, $p > .05$, indicating that there were no trade-offs between the memory and distracting task.

Reaction Time.

The mean RT for correct responses in the distracter tasks is presented in Table 2, for each condition. Data were once again analyzed in a 2 (Distracter task) x 2 (Attention) x 5 (Task order) ANOVA. There were no main effects or interactions involving Task order. We found a main effect of Distracter task, F (1, 25) = 9.27, MSE = 13474.56, $p < .01$, with longer RTs in the word than digit task. There was also a main effect of Attention, F (1, 25) = 200.61, MSE = 6696.46, $p < .001$, with longer RTs in the dual than single-task conditions. There was, however, no Distracter task X Attention interaction, F (1, 25) = .01, $p > .05$, indicating that the increase in RT from single to dual task conditions was equivalent for the digit and word-based distracter task.

We also examined the percentage increase in RT, by subtracting single task RT from dual task RT, dividing by the dual task RT, and then multiplying the value by 100 (see Table 7). We did not find a main effect of Distracter task, F (1, 25) = .95, $p > .05$.

Distracting Task Performed Concurrently with the Auditory CRT Task.

We again compared resource demands of the distracter tasks by having participants perform each distracter task with an auditory continuous reaction time (CRT) task. We examined CRT task performance alone, and in combination with each of the distracting tasks, as well as accuracy for each distracting task when performed concurrently with the CRT task. Due to a computer error, the data of one subject was lost.

Auditory CRT Data.

The mean RT to identify correct tones was analyzed using a 3 (Attention) x 2 (Task order) ANOVA, with the first variable being a within-participant and the second variable a between-participant manipulation. There was no effect of task order in any of the analyses. Mean RT for the single, dual digit and dual word conditions were 724.61 (SD = 139.36), 1110 (SD = 219.92), and 1139.64 (SD = 259.53) respectively. We found a main effect of Attention, F (2, 54) = 73.48, MSE = 42073.68, $p < .001$, with simple effects analyses showing faster reaction times in the single CRT condition than in the dual digit CRT, F (1, 27) = 109.38, MSE = 39000.16, $p < .001$, and the dual word CRT task, F (1, 27) = 101.44, MSE = 49105.55, $p < .001$. Importantly, RT in the dual digit CRT and dual word CRT conditions did not differ, F (1, 27) = 0.73, $p > .05$.

The mean number of tones identified was also analyzed using a 3 (Attention) x 2 (Task order) ANOVA. Again, there was no effect of task order in any of the analyses. The mean number of correctly identified tones was 99.24 (SD = 20.61) for the single, 59.41 (SD = 16.49) for the dual digit, and 56.51 (SD = 18.02) for the dual word conditions. We found a main effect of Attention, F (2, 54) = 181.15, MSE = 90.48, $p < .001$. Simple effects analyses showed that the number of tones identified was higher in the single CRT condition than in the dual digit CRT, F (1, 27) = 199.17, MSE = 228.50, $p < .001$, and the dual word CRT conditions, F (1, 27) = 268.87, MSE = 195.57, $p < .001$. Importantly, there was also no difference in the number of tones identified in the dual digit and dual word tasks, F (1, 27) = 2.15, MSE = 118.82, $p > .05$.

Distracting Task performed concurrently with CRT data.

Distracting task accuracy (hit rate – false alarm rate) was calculated and analyzed using a 2 (Distracting task) x 2 (Task order) ANOVA. Distracter task accuracy rate was 0.59 (SD = 0.20) in the dual digit condition and 0.58 (SD = .22) in the dual word condition. Analyses showed that the main effect of Distracting task was not significant, F (1, 27) = 0.02, MSE = .05, $p > .05$, indicating that distracting task performance did not differ between conditions.

3.3.3 Discussion

We again found that during both the DA-digit and DA-word condition, Remember false alarms increased, compared to the FA condition, indicating that there is a general interference effect from DA conditions at retrieval, on Remember responses. In addition, we found that the DA-word condition selectively disrupts Know responses, as indicated by the decline in K responses in the DA-word but not DA-digit condition in measures of K accuracy, K d', and independence measures of knowing. Thus there is a material-specific interference effect on familiarity-, but not recollective-based, memory processes (these findings are discussed further in the General Discussion).

Since the pattern of effects did not change, even when the digit-based task was made more difficult, we do not believe that differences in task difficulty of the distracting tasks can account for our novel pattern of results in Know responses. Specifically, we found that accuracy in the word-based and digit-based distracter tasks did not differ during single task conditions. Although we did find that there was a decrease in accuracy and increased latency to respond to distracting task items in the DA word condition, we once aging found that the percentage increase in RT from FA to DA conditions did not differ across distracting tasks. These results strongly suggest that differences in level of difficulty between the distracting tasks cannot fully account for the pattern of results. In addition to this, when the distracter tasks were performed concurrently with the CRT task, there were no differences in distracter task accuracy, number of tones identified, or RT to identify tones.

3.4 General Discussion

The purpose of these two experiments, in Study 2 of this thesis, was to examine the attentional requirements, during retrieval, for recollection and familiarity-based recognition, and also to examine how general and material-specific manipulations of attention during retrieval affect the qualitative nature of the memories that are retrieved. We asked younger and older adults to make R, K or N memory judgments to words while concurrently performing either a digit- or word-based distracting task, and noted both general and material-specific interference effects. We found that DA at retrieval led to an increase in false Remember responses in both DA conditions, representing a general effect of DA on recollection. Additionally, we found a material-specific interference effect of DA on familiarity, in that it was reduced only when the distracter task contained similar material as the memory task, and this pattern did not differ across age groups.

General Interference Effects

As expected, we found that older adults made fewer accurate recollective responses than younger adults, as indicated by their elevated false alarm rate, and reduced recollection accuracy and sensitivity, across all experimental conditions, supporting previous studies that show older adults are less able to remember specific details of past events (Norman & Schacter, 1997; Schacter, Koustaal, & Johnson, 1997). With respect to the effects of DA at retrieval, we found that both younger and older adults made more false R responses during both DA conditions (see Figure 11). That the magnitude of the increase in R false alarm rate did not differ across DA conditions suggests that manipulations of attention at retrieval have a general effect on recollective-based memory processes. This finding also suggests that differences in level of difficulty cannot account for the differential effect of our word- compared to digit-based distracting task on knowing. If this had been the case, then the DA-word condition should have had a greater disruptive effect on R false alarm responses as well, but it did not.

Research has consistently found that new items can be given recollective-based responses (Holmes, 1998; Lane & Zaragoza, 1995; Norman & Schacter, 1997; Payne, Elie, Blackwell, & Neuschatz, 1996; Roediger & McDermott, 1995), and that under certain conditions false recollective responding can exceed false familiarity responding, such as when new items are semantically related (Payne et al., 1996) or belong to the same object category as old items (Israel & Schacter, 1997). False recollective responding has been explained in terms of impaired source monitoring (Gallo & Roediger, 2001; Higham, 1998; Lane & Zargoza, 1995), the improper assignment of old contexts to new items (Holmes, Walters, & Rajaram, 1998), an inability to inhibit or control gist-related processes (Balota, O'Dolan & Duchek, 2000) or 'phantom recollection' (Brainerd, Wright, & Morjardin, 2001). Regardless of the mechanism by which false R memories are produced, our study suggests that availability of attention during retrieval is critical to avoid such memory errors.

Our claim that accurate recollection is reliant upon available attentional resources at retrieval is in contrast to Gardiner, Gregg, & Karayianni (2006) suggestion that reduced resources at retrieval do not affect recollection. The discrepancy in our findings may be due to the different methods used to manipulate attentional resources across the two studies, or because Gardiner et al. did not perform a separate analysis on false alarm data. Nonetheless, our findings support dual process theories of recognition memory that suggest recollection is a more attention demanding process than familiarity at retrieval (Jacoby, 1991; Yonelinas, 2001).

We also found that older adults were more likely than younger adults to produce R false alarms in both FA and DA conditions. With respect to age, several studies have found that older adults are more inclined to falsely recall and recognize information than younger adults (Norman & Schacter, 1997; Rankin & Kausler, 1979; Smith, 1975). For example, older adults show higher false recognitions to semantically related lures on recognition memory tests (Norman & Schacter, 1997; Schacter, Israel & Racine, 1999), as well as greater source misattribution errors (Craik & McIntrye, 1975; Mitchell, Johnson & Mather, 2003). Patients with frontal lobe dysfunction often show elevated rates of false recognition (Curran, Schacter, Norman, & Galluccio, 1997; Melo, Winocur & Moscovitch, 1999; Parkin, Bindschaedler, Harsent & Metzler, 1996; Schacter, Curran, Galluccio, Milberg & Bates, 1996), and research suggests that the increased rate of false remembering shown in older adults is a result of age-related changes in the integrity of frontal lobe structures (Butler, McDaniel, Dornburg, Roediger, 2004; Craik & McIntyre, 1975; Craik, Morris, Morris, & Loewen, 1990).

Our finding that false alarm rate increases under DA conditions suggests that at least one of the reasons that older adults show elevated false remembering is that they are unable to engage in the attentional processes required to properly retrieve the contextual information during memory retrieval. Although the effect of DA did not interact with Age group, older adults made more false R responses overall, and showed a trend toward greater susceptibility to false alarms than younger adults under DA conditions. This finding is expected if increases in false remembering in seniors are linked to availability of attentional resources.

Material-specific effects on memory

We found that recognition memory performance declined during the DA-word, but not DA-digit task, as compared to FA, and that the amount of memory interference was similar in younger and older adults. This replicates past work showing that memory retrieval can be disrupted if the distracter task competes for similar content representations (Fernandes & Moscovitch, 2000, 2002, 2003; Fernandes et al., 2005, in press).

Importantly, we also found that this material-specific interference acted specifically on K measures of accuracy, false alarm rate, d’, and independence measures of familiarity, and not R, responses (see Figures 10 & 12). This finding suggests that familiarity-based memory retrieval relies on the reactivation of content representations, as it is disrupted specifically when the distracting task material is similar to that in the memory task. This claim is supported by other studies that have shown that familiarity, and not recollective-based, responding is affected when processing is disrupted by another variable or task, whose material is similar to that of the memory task. For example, flashing a prime before item presentation (Rajaram, 1993; Kinoshita, 1997) decreases K more than R, and performing an auditory lexical decision task followed by an auditory test of recognition memory has a detrimental effect on accuracy of knowing, when lures in the recognition task were created from the non-words in the preceding lexical decision task (Dewhurst & Hitch, 1997). Although these data cannot determine whether familiarity is best described as changes in processing fluency (Kelley & Jacoby, 1998; Rajaram, 1996), a quantitative memory strength (Yonelinas, 2001) or retrieval from semantic memory system (Tulving, 1983, 1985), these studies, together with ours, provide evidence that familiarity-based memory retrieval relies on the ability to properly engage in either the perceptual or conceptual processes that re-create the content of the memory.

In line with other work (Friedman & Trott, 2000; Java, 1996; Parkin & Walker, 1992; Perfect, Williams, & Anderton-Brown, 1995), we also found that older adults were equally accurate when making K responses as younger adults. That the reduction in K responding during the DA-word condition was equivalent in younger and older adults, suggests the processes supporting familiarity-based retrieval are relatively intact in older adults.

Our study also showed that R responding was unaffected during the DA-word condition (see Figure 10 & 12; grey bars). This suggests that during recollection, the content of memories must be accessed via a different network than during familiarity-based retrieval; otherwise R accuracy should have also decreased in the DA-word condition. At this point we can only make speculations as to what the exact mechanisms of this network may be. Since recollection appears to involve additional PFC processing (Eldridge et al., 2000; Henson et al., 1999; Wheeler & Buckner, 2004), it may be that there are alternate ways of accessing the content of memories that is distinct from the network of brain regions recruited during familiarity-based responding. However, the exact nature of how recollection is preserved during conditions of material-specific interference will need to be investigated in future research.

Distracting task performance

Previous work has also examined performance on the distracting tasks (Anderson et al., 1998; Craik & McDowd, 1987; Whiting & Smith, 1997), as an indicator of the component processes critical for retrieval, and has found that older adults have larger distracting task costs, under DA conditions, than younger adults. In the present study we found a general interference effect of DA on distracting task performance, with increased costs to performance during DA conditions (relative to full attention), and that this increase was greater for older adults. Such a finding corresponds well with past research suggesting that attentional resources are required to establish and maintain a retrieval set during memory retrieval, that distracting task costs provided an index of these resource requirements, and that older adults have a more difficult time establishing and maintaining set (Anderson et al., 1998; Craik & McDowd, 1987; Whiting & Smith, 1997).

Conclusions

The present set of experiments show two novel findings. First, we found that two different DA conditions at retrieval significantly increased false Remember responding, suggesting that general attentional resources may be required to properly search and/or monitor the retrieval of contextual memories. Second, we found a selective decrease in Know responses only during a word-based DA condition at retrieval, indicating a material-specific effect on familiarity. Aging was associated with decreased accuracy in Remember, but not Know, responses, compared to younger adults, and with increased latency in distracting task responses under DA conditions. Results suggest that recollective processes at retrieval rely on attentional resources, whereas familiarity processes rely on the reactivation of content-specific representations.

Chapter 4

Summary of Studies and General Discussion

We examined how general and material-specific manipulations of attention disrupt the neural and cognitive processes relating to memory retrieval in younger and older adults. The pattern of results can be summarized into four main findings. First, we found that conditions of DA alter the neural networks used during memory retrieval, and that the degree to which the network is altered is greater for material-specific than general manipulations of attention, mirroring behavioural performance (Study 1). General manipulations of attention were associated with increased prefrontal cortex activity, suggesting that additional attentional resources are required to perform successful memory retrieval under conditions of DA. In addition, material-specific manipulations of attention significantly disrupted the recruitment of a medial-temporal memory network, supporting the hypothesis that during material-specific interference, the ability to access the content of the memory trace is disrupted. Second, we found that the neural networks engaged during memory retrieval change with age, during both FA and DA conditions (Study 1). We found that, unlike younger adults, older adults' successful memory performance was related to activity in a right parahippocampal region, rather than a medial-temporal network, during all three memory conditions. This suggests that the role of the medial-temporal lobe in memory retrieval changes with age, and those older adults may be using a different memory network to access the content of the memory trace. In addition, during general manipulations of attention, older adults were found to recruit additional prefrontal activity, supporting the hypothesis that older adults require additional attentional resources to establish and maintain a retrieval set during memory retrieval. Third, we found that older adults had higher levels of false recollective responding, and that when the amount of attentional resources available during memory retrieval was reduced by divided attention (DA), false recollective responding increased (Study 2). This suggests that attentional resources are required to successfully search and/or monitor the retrieval of contextual memories (which characterizes R from K responses) and that a reduction of these resources with age may contribute to age-related deficits in recollection. Lastly, we showed that there is a selective decrease in Know responses only during material-specific manipulations of attention, indicating that when there is competition for the access of the content of the memory trace, familiarity processes are disrupted (Study 2).

When we examine these studies in combination, we can see numerous links between them. First, the data show that during general manipulations of attention, increased attentional resources, as indexed by prefrontal cortex activity, are recruited, and more of these are needed in old age. In addition, general manipulations of attention lead to an increase in false Remember responses, and this is amplified by old age. Although it is beyond the scope of this thesis, such findings suggest that when PFC resources are reduced, either because they are engaged by a distracter task, or lost with age, source confusions develop, leading to an increase in false Remember responses. Thus, it may be that a loss of attentional resources, due to a change in the integrity of frontal lobe structures, alter the neural networks used to mediate memory retrieval, and that this change contributes to age-related deficits in recollective processing.

Second, we found that successful memory performance was predicted by activity in different brain regions in younger and older adults. Whereas younger adults used a hippocampal-parieto-temporal network during retrieval, older adults recruited a rhinal-frontal network. There is some evidence that changes in medial temporal lobe regions may also contribute to age-related deficits in recollective processing. Daselaar et al. (2006) used neuroimaging techniques to examine how changes in the brain with age affect recollection and familiarity. They found that activity in a region of the hippocampus relating to recollection was reduced by aging, but that familiarity-based activity in the rhinal cortex increased with age. This suggests that changes in either frontal and/or medial temporal functioning with age contributes to a shift in the neural network used during memory retrieval, and that this corresponds to a change in the qualitative nature of the memory retrieved.

Third, we examined how memory retrieval is disrupted when the processes used to access the content of the memory trace are disrupted. We found that the neural network engaged during FA and DA-digit conditions was unassociated with the DA-word condition in both younger and older adults (Study 1), and that familiarity-based responding decreased only during the DA-word condition (Study 2, Experiments 1 and 2). It may be that the neural changes during material-specific interference relate specifically to a disruption in familiarity-based and not recollective based processing. We also found that during material-specific manipulations of attention, the hippocampal network used by younger, but not older, adults to reactivate the content of the memory trace was disrupted. However, although younger and older adults used different networks to retrieve the content representations of the memory, we found that both age groups had an equal decline in familiarity-based processing during the DA-word condition. Thus, although younger and older adults are using different networks during memory retrieval, material-specific interference produced a similar amount of disruption in Know responses. This may indicate that, despite the fact that older adults recruit a different neural network to access the content of the memory trace during memory retrieval, this new network is similarly affected by conditions that cause competition for the memory trace. In addition, since recollective responses were unaffected during the DA-word condition, these data suggest that recollective-based memories can be accessed via a different network in younger and older adults during material-specific interference.

These findings all converge on the notion that changes in neural processing during general and material-specific manipulations of attention affect recollection and familiarity through separate mechanisms, and that these mechanisms may change with age. In the future we hope to make further connections between the changes in neural and cognitive processing found in these two studies.

4.1 Directions for Future Research

In future work we hope to establish a direct link between changes in brain function and changes in recollective and familiarity-based responding, brought on by division of attention during retrieval, by using functional Magnetic Resonance Imaging (fMRI) in conjunction with the Remember-Know technique.

In a recent review of the neuroimaging and lesion data that have used a dual-process framework, Skinner and Fernandes (manuscript in preparation) proposed a neurocognitive model of recognition memory that differentiates recollection and familiarity in two respects. First, we suggested that although both recollection and familiarity rely on activity in frontal and parietal brain regions, recollection involves additional activity in the hippocampus, frontal and sensory (i.e., visual and auditory cortex) cortical brain areas. Secondly, we proposed that the strength of the connection between frontal and parietal areas may be more coherent during recollection than during familiarity-based responses. That is, during recollection the frontal lobes may help instantiate the correct context to accompany a feeling of familiarity, which is established by a medial temporal/parietal network that initiates the reactivation of the content of the memory trace. During familiarity, however, the connection between frontal and parietal regions may be weaker. Thus the familiarity signal can be thought of as a lack of coherence between brain regions, compared to the recollection signal, which is characterized by stronger weights between contributing brain regions.

We intend to use fMRI to examine brain activity while participants make 'Remember', 'Know', and 'New' judgments during memory retrieval performed with either no distracting task (FA), a digit-based distracter task (DA-digit), or a word-based distracter task (DA-word). We then hope to use both univariate and multivariate imaging analyses methods to test the following predictions:

Univariate Imaging Analyses

1) In younger and older adults, under FA conditions, we would expect recollective processing to require greater frontal and medial temporal activity than familiarity-based processing. Since older adults are believed to have fewer attentional resources to begin with, however, older adults should show increased prefrontal activity during recollective processing. This increased PFC may relate to the decline of recollective processing in older adults, since recollection requires more neural resources than familiarity, which are limited in older adults. In addition, during familiarity-based processing, we may also see that older adults require greater PFC resources than younger adults; however, since familiarity requires less PFC resources than recollection, this increase should not affect familiarity-based responding in older adults. Lastly, we may see changes in medial temporal lobe function during recollective and/or familiarity-based responding in medial temporal lobe regions, with a shift from hippocampal to parahippocampal processing shown with age.

2) During the DA-digit condition (general manipulation of attention), PFC activity should increase in both younger and older adults, as greater attentional resources are required during this condition. However, since recollection initially requires greater attentional resources than familiarity, the increase in PFC activity only affects recollective responses, by increasing the number of false Remember responses in this condition. In addition, during the DA-digit condition, Fernandes et al. (2005, 2006) found that medial temporal activity was reduced in younger adults, and parietal activity was increased in older adults, as compared to FA. This suggests that increases in PFC activity during DA conditions may relate to changes in how the brain accomplishes memory retrieval, and that the manner with which the brain responds to DA changes with age; however, whether these changes relate to recollection and/or familiarity-based responding, and how they may relate to behavioural outcomes, is unknown.

3) Lastly, during the DA-word condition, we expect that activity in brain regions that relate to memory retrieval in younger and older adults will be disrupted. Fernandes et al. (2006) found that activity in the right hippocampus decreased during the DA-word condition in younger adults as compared to FA and the DA-digit conditions. Replicating these results, we would expect that right hippocampal activity will decline during the DA-word condition in younger adults. However, whether this decrease will be found for only familiarity-based responding (i.e., during material-specific interference, recollection may proceed unimpeded), or for both recollective and familiarity-based responding (i.e., material-specific interference disrupts both types of processing but recollection can proceed via some other neural network), is unknown. In addition, since Fernandes et al. found that older adults did not modulate hippocampal activity during the DA-word condition, this suggests that they are using other brain regions to access the content of the memory traces. However, at this point we are unable to make specific predications about what these brain regions may be, and how they relate to recollective and familiarity-based processing.

Multivariate Imaging Analyses

Following these univariate analyses, we then plan to use Partial Least Squares (PLS) to test the following predictions relating to the neural networks used in younger and older adults during recollective and familiarity-based memory retrieval:

1) A Task PLS should show that similar neural networks are recruited for recollection and familiarity responses, but that the value of the design score, (a numerical index of the strength with which a particular condition (or set of responses) shows a particular pattern of brain activity), should be higher for recollective-based, than familiarity-based, responses. Such findings would suggest that while the recollective and familiarity memory processes may call on similar neural structures, the nature of the connections between regions is dissimilar. In addition, since there is a disruption in familiarity-based processing during the DA-word condition, this condition should be unrelated to the network (have a design score of zero). Lastly, with respect to age, we should see that the Task PLS is less able to differentiate recollective and familiarity-based responses in older adults (i.e., the numerical values of the design scores should be similar), since the ability to engage the unique neural processes relating to recollective responses are presumed to decline with age.

2) In order to examine the increase in false recollective responding during general manipulations of attention, we would perform a Seed PLS functional connectivity analysis with a PFC region as the seed. If the increase in false recollective responding is related to a competition for PFC resources, we would expect to see that PFC activity is related to successful memory performance under FA, but not the DA-digit or DA-word, condition.

3) Lastly, in order to establish a direct connection between the hippocampal network used to index the content of the memory trace and familiarity-based processing, we would perform a Seed PLS using a hippocampal region as the seed. This should show that a hippocampal-network is related to successful familiarity-based retrieval during FA and DA-digit conditions, but not the DA-word condition. How this network will respond to recollective-based responses, however, is less certain. There is the possibility that during recollection, this network is not accessed and the content of the memory trace is accessed via a

completely different network. In contrast, it may be that this network is used for both recollection and familiarity during the FA and DA-digit condition and that only during the DA-word condition, when the network is interfered with, do recollective processes access the content of the memory through different neural mechanisms.

4.2 Summary of Studies

The studies show four main findings. First, conditions of DA affect the neural networks used during memory retrieval. Secondly, younger and older adults use different neural networks during memory retrieval, and the manner with which these networks respond to general and material-specific manipulations of attention change with age. Third, DA during retrieval affects the ability to accurately retrieve information by increasing false memories during any DA condition. Fourth, familiarity-based processing can be disrupted by certain DA conditions, namely those in which the distracter task items contain materials similar to the memory task. Together, the results suggest that recollection and familiarity require unique processing resources, and that changes in brain activity resulting from aging and DA may affect the qualitative nature of the memory retrieved.

By using the DA technique, we are able to determine the cognitive resources required for retrieval, and how these requirements change with age, at both the neural and behavioural level. These findings have implications for our understanding of how memory retrieval is accomplished, as well as how the neural and cognitive processes engaged during retrieval affect the qualitative nature of our the memories we retrieve. In the future, I hope to further increase our understanding of memory by examining the neural resource demands of recollection and familiarity, as well as how neural changes associated with aging lead to a change in the mechanism and type of memories that are retrieved.

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