Divided attention effects on retrieval
from episodic memory

by

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A thesis submitted in conformity with the requirements for the Degree of Doctor of Philosophy

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Divided attention effects on retrieval from episodic memory

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Abstract

In this thesis the dual-task technique is used to infer the component processes involved in episodic memory retrieval. In each of the six experiments, participants studied a list of random words under full attention, and recalled them while performing a distracting task presented visually on a computer. Previous research suggested that divided attention (DA) during retrieval disrupts free recall for words if the distracting task also involves memory for verbal material (Fernandes & Moscovitch, 2000). The purpose of the present work was to determine more precisely which factor(s) modulated this effect, and influence retrieval success. In the first experiment I found that verbal distracting tasks, that required animacy or syllable decisions to words, produced large interference on memory. Experiments 2 and 3 showed that phonemic decisions about nonsense-words produced a similarly large interference effect on memory, that was larger than semantic decisions or size-estimations about pictures of objects. These findings support the component-process model of memory, which suggests that retrieval is largely disrupted only when there is competition for a common representational system. In the next set of experiments an alternative, reduced-resource, account of interference from DA at retrieval is considered by comparing the performance of young and old adults under DA conditions. A word-animacy distracting task interfered substantially with retrieval, but the size of the effect was not amplified in old compared to young adults. Dividing attention using an
odd-digit task did not produce as large an effect, in either group. Finally, the contribution of the frontal and temporal lobes to interference effects on memory were examined. Elderly participants were divided pre-experimentally into 4 groups, determined by their scores on measures of frontal and temporal lobe function, derived from neuropsychological testing. Large interference effects on memory were produced by the animacy, but not the odd-digit distracting task. The pattern and magnitude of interference effects did not differ depending on level of temporal or frontal function. These results do not support the hypothesis that effects of DA at retrieval are due to a reduction in general processing resources, attentional capacity, or competition for memory structures in the temporal lobe.
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Table of Contents

Abstract ii
Acknowledgements iv
Table of Contents v
List of Tables vii
List of Figures ix
List of Appendices x
Chapter 1: Introduction
   The dual-task technique 4
   Use of dual-tasks in other work 5
   Review of literature on DA effects at encoding and retrieval 7
   A model of memory retrieval 11
   Overview of experiments 15
Chapter 2: Factors modulating DA effect at retrieval 17
   Overview of Chapter 2 17
   Experiment 1 18
   Experiment 2 34
   Experiment 3 46
   General Discussion of Chapter 2 Experiments 60
Chapter 3: DA in young and old adults 69
   Overview of Chapter 3 71
Experiment 4 73
Experiment 5 88
Experiment 6 96

General Discussion of Chapter 3 Experiments 115

Chapter 4: General Discussion 128

Summary of Experiments 128

References 145

Appendices 164
List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Experiment 1 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Decline From Single to Dual-task Condition For Each Measure</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>Experiment 1 - Number of Correct Responses, Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>Experiment 2 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Decline From Single to Dual-task Condition For Each Measure</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>Experiment 2 - Number of Correct Responses, Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition</td>
<td>43</td>
</tr>
<tr>
<td>5</td>
<td>Experiment 3 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Decline From Single to Dual-task Condition For Each Measure</td>
<td>52</td>
</tr>
<tr>
<td>6</td>
<td>Experiment 3 - Number of Correct Responses, Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition</td>
<td>55</td>
</tr>
<tr>
<td>7</td>
<td>Experiment 4 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Change From Single to Dual-task Condition For Each Measure for young adults (N=24)</td>
<td>79</td>
</tr>
<tr>
<td>8</td>
<td>Experiment 4 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Change From Single to Dual-task Condition For Each Measure for older adults (N=24)</td>
<td>80</td>
</tr>
<tr>
<td>9</td>
<td>Experiment 4 - Number of Correct Responses, Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition for young adults (N=24)</td>
<td>84</td>
</tr>
</tbody>
</table>
10 Experiment 5 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Change From Single to Dual-task Condition For Each Measure for older adults (N=16)

11 Mean Characteristics (M + SD) of Groups Selected According to Frontal Lobe (FL) Function and Medial Temporal Lobe (MTL) Function, and Estimates of Published Normative Data on Neuropsychological Tests for Adults Aged 65 to 75 Years.

12 Experiment 6: Number of Words Recalled and Percentage Change From Single to Dual-task Condition For Each Measure in Each Group

13 Experiment 6: Additional Words Recalled Following each Divided Attention Condition for Each Group

14 Experiment 6: Accuracy Rates on Distracting Tasks and Percentage Change From Single to Dual-task Condition For Each Measure in Each Group

15 Experiment 6: Reaction Times (in milliseconds) on Distracting Tasks and Percentage Change From Single to Dual-task Condition For Each Measure in Each Group
List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mean percentage decline in free recall performance from full to divided attention (DA) for each condition in Experiment (Expt.) 1, 2, and 3.</td>
<td>62</td>
</tr>
<tr>
<td>2</td>
<td>Mean percentage decline in accuracy rate from single to divided attention (DA) for each condition in Experiment (Expt.) 1, 2, and 3</td>
<td>65</td>
</tr>
<tr>
<td>3</td>
<td>Mean percentage decline in free recall performance from full to divided attention (DA) for each condition in Experiment (Expt.) 4 and 5, in young and older adults.</td>
<td>117</td>
</tr>
<tr>
<td>4</td>
<td>Mean percentage decline in free recall from single to divided attention for older adults with relatively high versus low frontal lobe function with each distracting task.</td>
<td>119</td>
</tr>
<tr>
<td>5</td>
<td>Mean percentage decline in accuracy rate from single to divided-attention (DA) for each condition in Experiment (Expt.) 4 and 5, in young and older adults.</td>
<td>123</td>
</tr>
<tr>
<td>6</td>
<td>Mean percentage decline in accuracy rate from single to divided-attention (DA) in older adults with relatively high versus low frontal lobe function for each distracting task.</td>
<td>124</td>
</tr>
</tbody>
</table>
### List of Appendices

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Experiment 1 Instructions to Participants and Experimenter's tasks</td>
<td>164</td>
</tr>
<tr>
<td>1.2 Experiment 2 Instructions to Participants and Experimenter's tasks</td>
<td>171</td>
</tr>
<tr>
<td>1.3 Experiment 3 Instructions to Participants and Experimenter's tasks</td>
<td>178</td>
</tr>
<tr>
<td>1.4 Experiment 4, 5, and 6 Instructions to Participants and Experimenter's tasks</td>
<td>184</td>
</tr>
<tr>
<td>1.5 Instructions for auditory CRT task performed concurrently with each distracting task</td>
<td>190</td>
</tr>
<tr>
<td>2.1 Sample data collection sheet for free recall</td>
<td>192</td>
</tr>
<tr>
<td>3.1 Sample stimuli for distracting tasks in Experiment 1</td>
<td>193</td>
</tr>
<tr>
<td>3.2 Sample stimuli for distracting tasks in Experiments 2 and 3</td>
<td>194</td>
</tr>
<tr>
<td>3.3 Sample stimuli for distracting tasks in Experiments 4, 5 and 6</td>
<td>195</td>
</tr>
</tbody>
</table>
Chapter 1

General Introduction

There are theoretical reasons for wanting to study the effects of divided attention (DA) on memory. The degree to which attentional conditions influence what we take in and remember about the world provides a window on the capacities and limitations of human information processing. A surprising and counterintuitive finding in the memory literature is that episodic memory is disrupted easily when attention is divided during encoding, but less so during retrieval. Demonstrations within a laboratory setting, of a debilitating effect of DA on retrieval have been variable, and sometimes difficult to achieve. This is unexpected given that most people allege that retrieving information from memory, be it the name of a movie, familiar face, or answer to an exam question, is an effortful task, often thwarted by distraction.

The existence of an asymmetry in effects, on encoding and retrieval, is unexpected on the basis of traditional theories of memory. Several influential theorists have suggested that encoding and retrieval are similar or even identical, and they postulate a substantial overlap between the two processes. For example, Craik (1983) proposed that encoding processes are mainly those involved in perceiving and comprehending, and that retrieval processes operate in reinstating the same pattern of cognitive activity as at encoding, thereby allowing recollection of the event. In a similar vein, Tulving’s encoding specificity principle (1983; Tulving & Thomson, 1973), as well as the transfer appropriate processing theory (Morris, Bransford, & Franks, 1977; Roediger, Weldon, & Challis, 1989) also embody the notion that retrieval processes must reflect the specific operations that were carried out during encoding. Similarly, Kolers’ (1973) proceduralist view suggests that
we remember in terms of the operations or activities of encoding, hence the two are linked. Neuro-imaging and lesion studies also converge on the idea of similarity in encoding and retrieval processes: the same neural pathways activated when information is perceived and taken in, are again re-activated when that information is recovered (Mishkin & Appenzeller, 1987; Moscovitch, Kapur, Köhler, & Houle, 1995; Nyberg et al., 1995; Squire, Cohen & Nadel, 1984).

There are, however, indications that some brain regions are specifically active during one process and not the other. For example, the left prefrontal region has been consistently shown to be involved in encoding, whereas during retrieval, the right prefrontal region is more involved (Nyberg, Cabeza, & Tulving, 1996; Tulving et al., 1994; but see Wagner et al., 1998b who found that for both encoding and retrieval, inferior prefrontal activation was lateralized based on material type rather than mnemonic operation; and see Raye, Johnson, Mitchell, Nolde, & D'Esposito, 2000 who suggest retrieval may require interhemispheric interactions). Although there is work showing that the right prefrontal area is involved in encoding of non-verbal materials, such as unfamiliar faces (Kelly et al. 1998; Wagner et al., 1998b), the majority of studies indicate that encoding and retrieval activations are seen in opposite hemispheres. Likewise, if encoding and retrieval processes are indeed similar, experimental manipulations that affect one set of processes should have a similar effect on the other set, and not different effects as some studies have found. Birnbaum, Parker, Hartley, and Noble (1978) found that the effects of alcohol on memory encoding are sizeable, but its effects on retrieval are quite small. Along the same lines, Curran (1991) showed that benzodiazepines have a more negative effect on encoding than on retrieval.
With respect to attentional manipulations, it is well known that encoding is greatly affected when attention is divided, leading to poor memory (Anderson, Craik, & Naveh-Benjamin, 1998; Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Murdock, 1965; Naveh-Benjamin, Craik, Guez, & Dori, 1998). However, a different story emerges when the attentional manipulation is introduced only at retrieval. Some studies were able to demonstrate an interference effect with DA at retrieval, while others have found little if any indication of a deleterious effect (Anderson et al., 1998; Baddeley et al., 1984; Craik et al., 1996; Kellog, Cocklin, & Bourne, 1982; Naveh-Benjamin et al., 1998). Thus, the body of data to date demonstrates that memory performance is much more affected by DA at encoding than DA at retrieval.

Still more differences in the effects of DA at encoding and retrieval were found when performance on the distracting task is considered. Several researchers have noted substantially greater costs to distracting task performance when it is performed concurrently with retrieval (Johnston, Greenberg, Fisher, & Martin, 1970; Tumbo & Milone, 1971) as compared with encoding (Anderson et al., 1998; Craik et al., 1996; Griffith, 1976; Johnston, Griffith, & Wagstaff, 1972; Naveh-Benjamin et al., 1998). Moreover, as Craik et al. (1996) have shown, these asymmetrical effects are not a simple case of tradeoffs between tasks.

In this thesis I seek to understand the unanticipated small, and variable, effects of attentional manipulations on retrieval. I also plan to outline the component processes involved in episodic memory retrieval. The dual-task technique is used to allow inference of these processes, by measuring the occurrence and extent of interference effects on retrieval, from a concurrently performed task. The magnitude of effects from various
concurrent tasks, that use different types of material and/or processes, are compared. These data are used to develop a neuropsychological model of episodic memory. The model is then tested by considering how aging interacts with the observed interference effects. Further evaluation of the model, in terms of possible mediating brain regions, is carried out using a population of older adults classified by level of dysfunction in temporal and frontal lobe sensitive tests.

Since all of the studies in this thesis, and the conclusions drawn from them, make use of the dual-task paradigm, the first section reviews the technique and summarizes how it has been used in previous work. The next section reviews studies of the application of the dual-task technique to the study of encoding and retrieval of episodic memory. The final section outlines the model used to guide and interpret data in this thesis, and describes the rationale for the series of experiments that follow.

**The dual-task technique**

The dual-task or divided attention 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. 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 on one or both tasks when they are performed simultaneously.

For example, several studies have shown that different distracting tasks produce a distinct pattern of interference on target (primary) tasks, believed to be mediated by different brain regions. Martin et al. (1994) showed that letter and category fluency, which are mediated primarily by the frontal and temporal lobes, respectively, were differentially disrupted by distracting tasks believed to require the same resources and neural systems as each of the fluency tests. That is, an object decision task interfered more with category than letter fluency, and similar to Moscovitch (1994), a sequential finger-tapping task interfered more with letter than category fluency. 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.

**Use of dual-tasks in other work**

The dual-task technique has been used extensively to study the general processing capacity of humans. The single-capacity view of human information processing (e.g. Kahneman, 1973; Norman & Bobrow, 1975, 1976) was challenged based on results from dual-task experiments. While some tasks were shown to be difficult to perform simultaneously, such as shadowing spoken words and comprehending information in a second language (Moray, 1967, 1969), other tasks could be combined relatively easily. For example, Allport et al. (1972) found little interference between shadowing of words
and playing piano music, or recognizing pictures. Along the same lines, Brooks (1967) showed that reading, a visual task, was more difficult when performed concurrently with another task that required visualization, and less so with another task for which no visualization was used. Such results were incompatible with a single-channel view, and led researchers (Allport et al., 1972; Friedman et al., 1982; Kinsbourne & Hicks, 1978) to propose that humans have multi-channel processors and that it is only when the same processors are involved simultaneously in two tasks that performance will be difficult. Kinsbourne and Hicks subsequently attempted to understand the results of dual-task experiments by proposing that the degree of interference from simultaneous tasks is an inverse function of the “functional distance” between cerebral control centers. I will return to this point later in the general discussion as it bears on the interpretation of the present experimental data on episodic memory retrieval.

The dual-task technique has also been used to determine the characteristics of short-term memory. Specifically, the concept of ‘working memory’ proposed by Baddeley and Hitch (1974) drew its support from various experiments showing selective interference effects from dual-tasks. Their model posits a limited-capacity central executive, which coordinates the operations of “slave” sub-systems, the phonological loop and visuo-spatial sketchpad. These sub-systems provide temporary storage for verbal and visuo-spatial material respectively. Support for this idea came from studies showing a greater disruptive effect of unattended speech on short-term memory of words and digit-span (Baddeley, 1986) than on memory of visuo-spatial information (Logie, 1986).

Conversely, a visuo-spatial tracking task produced greater disruption on visual-imagery based tasks, than on tasks that were purely verbal (Brooks, 1968). Farmer,
Berman and Fletcher (1986) also found that verbal, but not spatial, reasoning was considerably impaired by rote rehearsal of digits; in contrast, spatial, but not verbal reasoning, was more disrupted by a concurrent spatial task. Thus, it is possible to use the dual-task technique to support the postulated existence of two different ‘slave’ sub-systems in Baddeley and Hitch’s (1974) model of working memory. Usually, interference effects from dual-tasks are attributed to competition for general processing resources, but as we see here, they can also be used to determine the characteristics of sub-systems involved in a model of working memory.

In this thesis, the dual-task technique is applied to the study of episodic memory retrieval. I use it to determine the component processes involved in retrieval, and to develop a model of memory.

Review of literature on DA effects at encoding and retrieval

Previous work used the dual-task technique to examine the resource requirements for encoding a list of items for a later memory test. Various distracting tasks such as card-sorting (Baddeley et al., 1984), digit-monitoring (Park, Smith, Dudley, & Lafronza, 1989; Murdock, 1965; Jacoby, 1991; Fernandes & Moscovitch, 2000), word-monitoring (Fernandes & Moscovitch, 2000), a visuo-spatial task (Craik et al., 1996; Naveh-Benjamin et al., 1998), and faces (Kellog et al., 1982) have been used. Despite procedural differences across studies, each of these distracting tasks was capable of interfering with encoding, as indexed by the large decline in memory performance, ranging from about 30-50%, following DA conditions.

Because such a variety of distracting tasks were capable of interfering with encoding, Craik et al., (1996), Anderson et al., (1998), and Naveh-Benjamin et al. (1998)
concluded that successful encoding demands general processing resources. In agreement with this speculation, Naveh-Benjamin and his colleagues (1998) have recently shown that the task used to divide attention during encoding must utilize general resources to be effective at reducing memory. From a neuropsychological perspective, Fernandes and Moscovitch (2000) suggested that interference from DA at encoding arises from competition for resources needed for conscious apprehension of material which is necessary for formation of a memory trace. Any distracting task that diverts resources necessary for conscious apprehension of that material, will lead to poor encoding, and poor formation of a memory trace.

Studies using the dual-task technique at retrieval, however, have not provided such a consistent view of resource requirements. On some tests (Dywan & Jacoby, 1990; Moscovitch, 1994; Park et al., 1989), DA at retrieval led to a substantial interference effect on memory performance (though not as severe as that associated with DA at encoding). In other studies, however, DA at retrieval had little, if any, effect on memory performance (Anderson et al., 1998; Baddeley et al., 1984; Craik et al., 1996; and Naveh-Benjamin et al., 1998). The lack of an effect of DA at retrieval is surprising, given that it is experienced as such an effortful process.

As the relatively small or non-existent interference effect of DA at retrieval was unexpected, I will examine these studies more closely. Baddeley et al. (1984) used the dual-task technique to examine the role of attention in retrieval of long-term episodic memories. They considered the effect of DA on memory tests such as free recall, paired-associate learning and recognition, while subjects concurrently performed a card-sorting task, or simultaneously held a digit-load in mind. They concluded retrieval was automatic
because, in all of their experiments, DA produced either no reduction or only a slight reduction in memory performance, of about 5-10% less than under full attention conditions.

Along the same lines, Craik et al. (1996) had subjects perform free recall, cued recall or recognition tests of memory simultaneously with a visual continuous reaction time task. Only small interference effects on memory performance were observed, regardless of the memory test used; memory costs were highest for free recall (13% decline from full attention), lower for cued-recall (9%), and almost nil on a recognition test. However, they also examined how DA affected performance on the distracting task, as this measure also reflects the resources needed for retrieval. They showed that distracting task costs varied depending on the amount of environmental support offered by the memory task. Costs were greatest for free recall (26% increase from baseline), less for cued recall (14%), and least for recognition (7%).

To further examine the role of attention in mediating interference effects at retrieval, Craik et al. examined how performance, on the memory and distracting task, varied depending on which task was emphasized. Memory performance (on each test of memory) remained relatively stable, dropping only a small amount compared to full attention conditions, despite telling subjects to pay more, or less, attention to the distracting task. Thus changes in allocation of attention had relatively little effect on retrieval. Performance on the distracting task, however, varied considerably depending on how much attention was allocated to it. These results are in stark contrast to the effects they observed when attention was divided at encoding: memory performance varied systematically depending on the amount of attention allocated to the distracting and
memory task. That is, the more attention was paid to the distracting task, the worse
memory performance became, and vice versa.

Thus in contrast to encoding, which is sensitive to levels of available attention,
retrieval appears immune to disruption by DA. Because there were costs to the distracting
task, and these were sensitive to attentional manipulation, Craik et al. concluded that
retrieval, despite being immune to disruption, was resource-demanding and did not
proceed automatically. They suggest that general attentional resources are necessary for
placing the cognitive system into a retrieval mode, and for voluntary strategic operations
that elaborate and augment cues provided during retrieval.

Other work by Naveh-Benjamin et al. (1998) examined the resiliency of memory
retrieval to various task demands, when performed concurrently with a visual CRT task.
They considered whether DA at retrieval would affect memory performance, in a cued-
recall paradigm, more when low versus high frequency words were to be retrieved. Low
frequency words are harder to recall (Gregg, 1976), and may require more search
processes that could be disrupted under DA conditions. They also considered whether
different perceptual attributes, using a different versus same voice at retrieval as at study,
would increase the effect of DA. Neither of these manipulations altered the resiliency of
retrieval to DA conditions. As in previous studies, DA had little if any effect on retrieval,
regardless of whether memory was for low or high frequency words, or for items studied
in the same or different voice as at study. There were, however, significant costs to the
distracting task, which varied depending on the memory task demands. These studies
strongly suggest that memory retrieval is immune to disruption, and runs obligatorily,
though it does consume general attentional resources as indicated by costs to the distracting tasks.

**A model of memory retrieval**

These results can also be understood in the context of a neuropsychological model, which ascribes different memory functions to different brain regions. The component process model (Moscovitch & Umiltà, 1990, 1991) of memory suggests that a key factor that determines whether interference is created from DA at retrieval, is the extent to which retrieval is dependent on strategic processes mediated by the PFC, and on associate cue-dependent processes, mediated by the medial temporal lobe/hippocampus (MTL/H).

According to the model, frontally-mediated retrieval processes are resource-demanding whereas those mediated by the MTL/H are modular, and require fewer general resources for its operations. Examples of memory tasks that are frontally-mediated include recall of categorized lists (Moscovitch, 1994; Park et al., 1989; Stuss et al., 1994), list discrimination (Dywan & Jacoby, 1990; Jacoby, 1991), and release from proactive inhibition (Moscovitch, 1989, 1994). Under DA conditions, as long as the concurrent task is itself resource-demanding and draws resources away from the memory task, interference should be observed on the above tests. As predicted by the model, substantial interference effects from DA at retrieval were found using these tests; the effect is attributed to a reduction in general resources available to, and organized by the PFC.

Other memory tests do not rely as heavily on PFC. In those studies in which DA effects at retrieval were small, or even non-existent, (Anderson et al., 1998; Baddeley et al., 1984; Craik et al., 1996; and Naveh-Benjamin et al., 1998), the memory test consisted of free recall, cued recall or recognition of a list of unrelated words. Performance on these
tests is often disrupted by MTL/H damage, but rarely by frontal damage (Milner, Petrides, & Smith, 1985; Moscovitch, 1982a; Schacter, 1987b). As suggested by Moscovitch (1994), if the frontal lobe contribution to the memory test is minimal, then interference effects from DA at retrieval will be small, as retrieval can be performed by the modular MTL/H, which operates relatively automatically and obligatorily. Consequently, competition for general processing resources, drawn on and organized by the PFC, is not a factor that should affect memory performance on these tests. The only resource-demanding aspect of retrieval on these tests lies in establishing and maintaining retrieval mode, as well as monitoring output; such processes are thought to be mediated by the PFC, and under DA conditions, are reflected in costs to the distracting task.

In an effort to delineate further the processes involved in retrieval of episodic memories, I investigated in previous work with my supervisor, Morris Moscovitch, whether there are conditions under which DA does interfere with retrieval on tests mediated primarily by the MTL/H system (Fernandes & Moscovitch, 2000). Although others did not find very large interference effects on retrieval of a list of unrelated words (Anderson et al., 1998; Baddeley et al., 1984; Craik et al., 1996; and Naveh-Benjamin et al., 1998), close examination of the component-process model suggests some conditions that may lead to memory disruption. Rather than competing for general resources, a concurrent task during retrieval might compete with the structures needed to reactivate the memory trace.

According to the component-process model, the actual recovery of the memory occurs when the trace interacts with the MTL/H in a process called ephory. The trace is thought to consist of an ensemble of neurons in the neocortex that mediates the conscious
experience during encoding, and forms the perceptual representation responsible for the content of the experience. This trace is bound to the MTL/H, forming a consciousness-content packet that is the recovered memory (Moscovitch, 1995a,b). During retrieval, an internally-generated or externally-presented cue activates the MTL/H, which acts as a pointer or index to the neocortical neurons representing the content of the trace. A concurrent task at retrieval may disrupt either the MTL/H function, or the neocortical representation. That is, if the two tasks require access to the MTL/H system (needed to reactivate the neo-cortical representation), interference may occur on one or both tasks. Similarly, if the two tasks compete for the perceptual representation that is part of the memory trace, interference may also occur.

At a functional level, the crucial element in the first condition is that the target memory and concurrent task both involve memory, whereas in the second condition the crucial element is the similarity in the type of information that is processed in both tasks, regardless of whether the concurrent task involves long term memory (LTM), short term memory (STM), or simply perception. In my earlier work we tested these hypotheses (Fernandes & Moscovitch, 2000). I will briefly summarize these experiments as they form the basis for the studies included in this Ph.D. thesis.

In the first of the experiments, participants studied a set of 16 auditorily-presented words under full attention which they had to recall freely aloud after a 55 second, filled delay (15 seconds of arithmetic calculations and 40 sec of a distracting task). During recall in the DA condition, participants also had to monitor simultaneously a list of visually-presented words in a running recognition test. In one DA condition, some words were repeated after at a lag of 3 or less, and in the other DA condition, at a lag of 7 or
more, making each a test of short-term or long-term memory, respectively (see Tulving & Colotla, 1970). We found that both DA conditions were successful in producing a substantial decrement in recall of about 30% in comparison to the full attention condition. That there was no difference between the short and long lag conditions suggested that MTL/H, which is involved in long-term memory but not short-term memory, was not the locus of the competition effect between the target and distracting memory tasks. Instead, the results suggested that the locus of the effect was at the level of neocortical representational systems involved in word perception and production.

This conclusion was confirmed in subsequent studies. Instead of using running recognition as the interference task, we used word-monitoring. In an animacy-monitoring task, participants monitored a list of visually-presented words and indicated whenever words denoting living things occurred three times in succession. The effects of this interfering task, at encoding and retrieval, were compared with that of a visual reaction time task used by Craik et al (1996) (For details, see Fernandes & Moscovitch, 2000). Recall dropped by about 50% when digit-monitoring was performed concurrently with encoding, but only by about 10% when it was performed with retrieval. By contrast, the animacy-monitoring task, which had similar effects to digit-monitoring at encoding, led to a substantial 30% drop in recall when performed during retrieval. Thus, the results showed that interference effects from DA at retrieval were material-specific, but the effects at encoding were general.

These results are consistent with the hypothesis from the component-process model that interference at retrieval can occur when there is competition for representational structures, presumably in neocortex; competition for MTL/H structures
does not appear to produce interference. In contrast, at encoding, it is competition for general cognitive resources that largely determines the effects of DA on subsequent recall; reduction of conscious awareness by any means leads to poor formation of memory traces or engrams, thereby explaining the general effects of DA at encoding. At retrieval, recovery of memory traces via the MTL/H is obligatory and automatic unless a concurrently-attended stimulus competes with representations, likely in the posterior neocortex, that either form part of the recovered memory trace or that are needed to gain access to it.

**Overview of experiments**

The purpose of this thesis is to determine more precisely which variables are responsible for producing large interference effects on retrieval. I test whether the large DA effect at retrieval is material or process-specific, and if so, I attempt to determine which materials or processes are implicated. In so doing, I hope to specify the locus of interference effects at retrieval, and suggest possible underlying neural systems mediating memory retrieval. In Chapter 2, I tested whether competition for verbal mnemonic processes contributes to the production of large interference effects under DA at retrieval. I also consider whether it is the semantic or phonemic aspect of a distracting task that influences the size of the effect on memory retrieval. These data are used to develop further the component-process model described above, by specifying whether the neocortical representations, for memory of the word list, are semantic or phonemic. In Chapter 3, I consider whether an alternative resource account of DA effects at retrieval is tenable, by examining how aging interacts with the pattern of effects from distracting tasks that use different materials. I further evaluate the model, in terms of possible brain regions
mediating the effects, by considering performance under DA conditions in a population of older adults, classified by level of temporal and frontal lobe function.

In each of my experiments I used the methodology and memory task employed by Fernandes and Moscovitch (2000). The design eliminated the possibility of modality-specific interference, since presentation of the material for the memory task at study was auditory and recall was vocal, whereas the distracting tasks were always presented visually via a computer monitor, and the responses to it were manual.
Chapter 2

A curious finding in the memory literature is that episodic retrieval, for a list of unrelated words, is relatively immune to the adverse effects of DA manipulations. In recent work, however, I showed that retrieval can be disrupted depending on the type of material used in the concurrent task (Fernandes & Moscovitch, 2000). These experiments led to the suggestion that retrieval occurs obligatorily, such that recovery of the memory trace is unaffected by concurrent tasks, except those that compete for access to the same neocortical representational system as the memory trace.

In this chapter I use the dual-task technique to examine this proposal in more detail. Specifically, I wish to establish what aspect of the material in a distracting task is responsible for producing large disruptions in retrieval. Is the key factor competition for a common representation, or is competition for MTL/H memory structures also needed to produce interference? In an effort to further specify the locus of interference at retrieval, I also examine whether it is the semantic or word-form component of a distracting task that modulates the amount of disruption that is observed on memory. This information is then used to provide insight into the resource requirements for episodic memory retrieval.

Overview of Chapter 2

In the first experiment I investigated whether it was necessary to have a memory component in the distracting task to produce interference. All of the verbal distracting tasks from Fernandes and Moscovitch (2000) had a memory load, which left open the
possibility that interference effects potentially could be due to competition for memory structures rather than for a common, word-based representational system as they suggested. In this experiment, despite eliminating the memory component of the distracting task, I found that on-line processing in word-based tasks such as making animacy or syllable judgements, performed concurrently with retrieval, produced large interference effects. Furthermore, these effects were not modulated by the level of processing required in the distracting task, whether semantic or phonological. This suggested that the word-form aspect of items in the distracting task, rather than their semantic content, accounted for the large interference effect on memory.

Consistent with this suggestion, Experiments 2 and 3 showed that even a distracting task involving nonsense-words, that have no semantic content, produced comparably large effects on memory. A semantic distracting task involving pictures on the other hand, with no word-form component, produced a significant, but smaller, effect on memory. This work also showed that increasing the level of difficulty of the picture-based task, from Experiment 2 to Experiment 3, did not increase the size of the interference effect. Thus, I conclude that retrieval is affected maximally when a distracting task involves processing of word-forms.

**Experiment 1**

**Introduction**

This experiment sought to determine whether competition for verbal mnemonic processes contributes to the production of large interference effects under DA at retrieval. A possible confounding factor in Fernandes and Moscovitch (2000) was that all of their
distracting tasks required a memory load, which may account for the large interference effect they observed on memory (Craik, 2000). Thus the large effects of DA at retrieval potentially could be due to competition for memory structures rather than for a common representational system. Recognition of words previously seen in a long list of visually presented items was one of the distracting tasks used in their study (see Experiment 1 Fernandes & Moscovitch, 2000). Such a task requires a significant memory load, as participants have to keep several items in mind while encoding new items. This issue was addressed by showing that a word-monitoring task, which reduces the memory load for the distracting task, still created large interference effects at retrieval, while an analogous digit-monitoring task produced relatively smaller effects on memory. However, it is still possible that interference arose due to the memory load demands of their distracting task, rather than the verbal component, as Fernandes and Moscovitch (2000) suggested. It may be that keeping even a couple of items in mind for the word-monitoring task introduced a memory load which, perhaps in conjunction with competition for verbal perceptual representations, led to the large effects of DA at retrieval. By eliminating the memory load component of the task, it should be possible to determine whether or not it was crucial for producing large disruptions in retrieval performance.

The objective of the present experiment was twofold. First, I tested whether a distracting task that involved words, but no memory load, would still produce large interference on memory performance. I created two different verbal distracting tasks for this purpose. One was an animacy decision task in which participants decided whether each word in a list denoted a living or a man-made object. The other was a syllable
decision task in which participants decided whether each word in a list had two syllables. If material-specificity is the crucial factor producing large interference effects of DA at retrieval, reducing the memory load of the distracting task should not reduce the size of the interference effect. Such a finding would also support the claim that interference at retrieval arises from competition for a common representational system (Fernandes & Moscovitch, 2000). If, however, eliminating the memory load eliminates or reduces the interference effect, then I will have shown that competition for memory systems underlies the effect.

I also wished to investigate what aspect of the distracting task modulates interference effects on memory. I considered the type of word processing required in the distracting task as a potential factor influencing the DA effect. I compared the animacy and syllable distracting tasks as they required semantic, and phonological processing, respectively. If it is the semantic aspect of words that modulates the interference effect, then animacy decisions in the distracting task should lead to a relatively greater effect than phonological decisions in the syllable distracting task.

In addition to the effects of DA on memory performance, previous studies also considered performance on the distracting task. Craik et al. (1996) and Johnston et al. (1970) suggested that the retrieval process demands significant general processing resources, as indexed by the large decrements in distracting task performance under dual-task conditions at retrieval. Contrary to Baddeley et al.’s (1984) claim that retrieval occurs automatically, Craik et al. (1996) reasoned that memory retrieval occurs obligatorily (since they showed only small effects of DA on memory), yet demands
considerable resources. While Fernandes and Moscovitch (2000) showed that retrieval is not obligatory, at least when the materials or processes used in the memory and distracting task are similar, they concur with Craik et al. (1996) that retrieval is resource-demanding. Fernandes and Moscovitch (2000) suggested that establishing and maintaining retrieval mode, and/or monitoring output (not the associative-cue-dependent process or ecphory) is the general resource-demanding aspect of retrieval (and that costs to the distracting task are incurred regardless of similarity in material between the memory and distracting task. The present experiment examined whether recall, which is determined more by semantic than phonemic aspects, would have a greater effect on accuracy or reaction time (RT) in the semantic than in the phonemic distracting task.

Because the distracting tasks themselves are resource-demanding, the amount of general resources each uses may contribute to the size of the interference effect. To assess the relative resource demands of each task, I looked at the effect each had on a concurrently performed auditory continuous reaction time (CRT) task. In the CRT task, participants had to identify computer-generated tones as either low, medium or high pitched tones. The RT and number of correct responses in 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.

Method

Participants
Participants were 24\(^1\) undergraduate students at the University of Toronto who received either course credit or $10.00 for their participation. All participants claimed to be native English speakers, and to have normal or corrected to normal vision and hearing.

**Overview of experiment**

Participants were asked to try to commit an auditorily presented list of words to memory and subsequently a free recall task was administered as the target memory task. Prior to retrieval they began a distracting task, either animacy or syllable decisions about words presented visually on a computer screen. In each of the two DA conditions, participants continued to perform one of the distracting tasks while simultaneously trying to recall out loud the target task word list. Participants also performed a baseline (full attention) condition, in which the distracting task ended prior to free recall.

**Materials**

**Target recall task** Stimuli for the target memory tasks consisted of 64 unrelated common nouns. Words for the target memory task were recorded in a sound-proof booth onto an audio file via a Macintosh computer using the Sound Designer II program. Four word lists were created by randomly choosing 16 words for each list from the pool of 64 words. Each word list was created with 3 seconds of silence inserted between words. Three beeps were also recorded prior to the beginning, and at the end of each word list. The lists were then recorded onto an audio-tape and presented via a cassette-player. All

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1 Data from one participant was excluded from Experiment 1 because of a misunderstanding of the task instructions. An additional participant was tested in his place. Data from the auditory CRT analysis for only 21 participants are included. Due to experimenter error, the data for three participants were invalid, and/or lost.
stimuli were medium to high frequency words chosen from Francis and Kucera (1982). Word frequencies ranged from 20–100 occurrences per million.

**Distracting tasks**

**Animacy decisions.** Four 50-word lists, and one 20-word list, consisting of words representing animals and man-made objects were created from a pool of 220 words. Each list was created such that half of the words represented animals and half man-made objects.

**Syllable decisions.** Four 50-word lists, and one 20-word list, consisting of one, two and three syllable words were also created from another pool of 220 words. Each list was created such that half of the words had two syllables, and the rest had one or three syllables. None of the words from the syllable and animacy task were used for both tasks. Also, none of the words in the syllable task represented animals.

All stimuli were medium to high frequency words chosen from Francis and Kucera (1982). Word frequencies ranged from 20–100 occurrences per million.

Words for the animacy and syllable decision task were presented visually on a computer screen at a rate of one word every 2 seconds. For the animacy participants indicated if presented words represented a man-made object, and for the syllable task, they indicated if the presented word had two syllables, by pressing a key with the dominant writing hand.

Although I recorded manual response times in all of these experiments, I did not emphasize to participants the importance of responding quickly on the distracting tasks, when performed singly and in dual-task conditions with retrieval. Nevertheless I analyzed
these data as they might provide an indirect indicator of level of difficulty or processing demands of each distracting task.

**Arithmetic task.** The study phase for the target memory task was always followed immediately by an arithmetic task to eliminate recency (as in Craik et al., 1996); participants heard a two- or three-digit number at the end of each word list, and were instructed to count aloud backwards by threes. The digits were recorded onto the audiorecorder in the same manner as the words for the target memory task.

**Procedure**

**Practice session.** Participants were tested individually. They performed the target memory task under full attention, followed by a practice session of the animacy and then syllable distracting tasks. The study phase for the target task was identical in the practice and experimental phase except that different lists were studied for each. For the memory task, participants heard a tape-recorded female voice reading a list of 16 words at a rate of approximately 1 word every 4 seconds, and were asked to try to commit the words to memory for a later recall test. Participants then counted backwards by threes starting with the digit spoken at the end of the word list for 15 seconds. In the practice phase, recall of the studied words occurred immediately following the arithmetic task. Participants had 60 seconds for free recall. Participants were then given a practice block for the animacy and then syllable distractor tasks.

**Experimental sessions.** Single-task performance for either the animacy or syllable distracting task was measured before any of the experimental conditions. Single-task performance for the remaining distracting task was measured at the end of the final
experimental condition. The order for determining single-task performance was
counterbalanced across participants.

Following the first single-task measure, the three experimental conditions (full
attention plus two DA conditions) were administered, counterbalanced across participants.
Presentation of the words for the target recall task was followed by the arithmetic task,
then either the animacy or syllable distracting task began. The distracting task was
performed alone for 40 seconds until the computer emitted a low-pitched tone. The tone
signaled that recall of taped words should begin. For the two DA conditions, the animacy
or syllable task continued on the computer while participants simultaneously tried to recall
words for the target task. The distracting and free recall tasks were performed
simultaneously for 60 seconds, and participants were told to divide their efforts equally
between the two tasks. The importance of placing 50% of their effort on the recall task
and 50% on the distracting task was emphasized. After recall in the DA conditions, the
experimenter asked participants if they recalled any additional words from the study list,
now that they did not have to do two things simultaneously. Participants' recall responses
were tape-recorded.

In the 'full attention' experimental condition, the distracting task ended after the
computer signaled that free recall should begin. Thus, in this condition recall occurred
under full attention, and served as a baseline with which to compare free recall in the DA
conditions. It should be noted that in this condition either the animacy or syllable task was
performed as a 'filler' for the first 40 seconds (using the 20-word list) after the study
phase of the target word list. In this way the time lag between when the words for the
recall task were studied, as well as the need to perform another task before recall, were
the same as in the DA conditions. The ‘filler’ task ended once the computer signaled that
recall of the taped words should begin. For all orders of experimental conditions,
participants were given a four-minute break before beginning the next condition.

Comparing resource demands of the distracting tasks.

The auditory CRT task was used to compare the resource demands of the animacy
and syllable distracting tasks. For this task, participants had to identify computer-
generated tones as either low, medium or high pitched tones. The tones were played in a
random order, and participants were told to press the appropriate key as quickly and as
accurately as possible to identify the tone on each trial. A new tone was presented as soon
as the participant pressed a key, or after 3 seconds had elapsed.

Each participant completed three sessions of this CRT task as the final phase of the
experiment. The task was performed alone for a baseline measure, and in DA conditions
with the animacy and syllable tasks. For the DA conditions, in order to avoid having
participants make different manual responses for the CRT and distracting tasks,
participants made a verbal response to identify words (man-made words for the animacy
task and two-syllable words for the syllable task). The experimenter recorded the
participant’s responses by pressing a key on a separate keyboard.

In the DA conditions, the tone task was performed alone for a short time, after
which one of the distracting tasks began and lasted 100 seconds. The RT and number of
correct responses in the auditory CRT were recorded and analyzed as a means of gauging
how demanding each distractor task was, with longer RTs indicating greater resource demands.

**Results**

**Target memory task.** Both the animacy and syllable distracting tasks interfered substantially with free recall performance. There was no difference in the magnitude of this effect depending on whether the distracting task was animacy or syllable decisions to words. The means for each condition are presented in Table 1. The data were analyzed in a two between (order of experimental condition and order of single-task measure for the animacy and syllable task) and one within (experimental condition) ANOVA. There were no significant main effects or interactions with the order factors, on free recall performance. The following results were significant at $p < .001$ unless otherwise noted.

There was a main effect of experimental condition $F (2, 46) = 21.70$, $MSE = 2.22$. The mean numbers of words recalled in both the animacy and syllable DA conditions were reduced significantly from the mean in the full attention baseline condition, $F (1, 23) = 56.62$, $MSE = 3.01$ and $F (1, 23) = 31.10$, $MSE = 3.62$, respectively. The difference in number of words recalled in the animacy versus syllable conditions was not significant, $F (1, 23) = 0.90$, $MSE = 6.70$. The mean percentage decline in words recalled for each participant, from full attention to DA conditions, did not differ for the two DA conditions.
Table 1: 
Experiment 1 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Decline From Single to Dual-task Condition For Each Measure

<table>
<thead>
<tr>
<th>Measure and condition</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target memory task</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words recalled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Attention</td>
<td>7.46</td>
<td>2.38</td>
</tr>
<tr>
<td>DA animacy</td>
<td>4.79</td>
<td>2.15</td>
</tr>
<tr>
<td>DA syllable</td>
<td>5.29</td>
<td>2.35</td>
</tr>
<tr>
<td>Percentage Decline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>35.33</td>
<td>23.00</td>
</tr>
<tr>
<td>DA syllable</td>
<td>28.43</td>
<td>23.48</td>
</tr>
<tr>
<td><strong>Distracting task</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline animacy</td>
<td>.79</td>
<td>.08</td>
</tr>
<tr>
<td>DA animacy</td>
<td>.61</td>
<td>.13</td>
</tr>
<tr>
<td>Baseline syllable</td>
<td>.75</td>
<td>.11</td>
</tr>
<tr>
<td>DA syllable</td>
<td>.51</td>
<td>.24</td>
</tr>
<tr>
<td>Filler</td>
<td>.62</td>
<td>.37</td>
</tr>
<tr>
<td>Percentage decline in accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>22.19</td>
<td>18.30</td>
</tr>
<tr>
<td>DA syllable</td>
<td>32.51</td>
<td>30.19</td>
</tr>
<tr>
<td>Reaction time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline animacy</td>
<td>842.88</td>
<td>104.99</td>
</tr>
<tr>
<td>DA animacy</td>
<td>1030.08</td>
<td>144.21</td>
</tr>
<tr>
<td>Baseline syllable</td>
<td>1059.50</td>
<td>188.74</td>
</tr>
<tr>
<td>DA syllable</td>
<td>1091.92</td>
<td>174.09</td>
</tr>
<tr>
<td>Percentage increase in reaction time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>16.94</td>
<td>13.60</td>
</tr>
<tr>
<td>DA syllable</td>
<td>1.74</td>
<td>19.12</td>
</tr>
</tbody>
</table>

Note: DA = divided attention
Following each DA condition, the participants were given the chance to recall words from the target task under full attention. Few participants recalled any additional words. The mean numbers of additional words recalled after the ‘animacy’ and ‘syllable’ DA conditions were only 0.54 (S.D. = 0.83) and 0.54 (S.D. = 0.93) respectively.

Distracting tasks

Accuracy rate.

Accuracy rates (calculated as #hits/15 - # false alarms/15) on the animacy and syllable distracting task, in the DA conditions, were much worse than under single-task conditions. The percentage decline in accuracy rate, from single to dual-task conditions, was larger on the syllable than animacy task but the difference was not significant. The data were analyzed in a two between (order of experimental condition and order of single-task measure for the animacy or syllable task) and one within (experimental condition) ANOVA. There were no significant main effects or interactions with the order factors on distracting task performance. There was a main effect of experimental condition, F (3, 69) = 19.45, MSE = 0.02. The mean accuracy rates for each task, in each condition, are presented in Table 1.

The mean accuracy rates on both tasks under DA conditions differed significantly from their respective single-task baseline performance (F (1, 23) = 30.96, MSE = 0.03 and F (1, 23) = 27.12, MSE = .05, for the animacy and syllable task respectively). Percentage decline in accuracy rate, from single to dual task performance, did not differ significantly across distracting tasks.

Reaction Time.
The mean RT to make a response, for each distracting task, in the single-task baseline and dual-task condition with retrieval is noted in Table 1. The baseline RT was significantly longer for the syllable than animacy distracting task ($t(22) = -5.49$). The percentage increase in RT, from baseline to dual-task conditions was significantly greater for the animacy than syllable task ($t(22) = 2.99, p<.01$).

The correlation between RT on the distracting task, and memory interference under each DA condition was non-significant.

**Auditory CRT**

**Distracting task.** The accuracy rate for both of the distracting tasks suffered to a similar degree when the auditory CRT task was performed concurrently. There was no effect of task order on accuracy rates. The mean accuracy rates on the animacy and syllable tasks, performed concurrently with the CRT tone task, were .44 (S.D = .23) and .46 (S.D = .22) respectively. The difference between these two accuracy rates was not significant.

**CRT tone task.** The difference in the number of tones correctly identified in the animacy and syllable DA conditions was not significant. The mean number of correct responses for each condition are presented in Table 2. A within participant ANOVA revealed a main effect of condition $F (2, 40) = 82.17, \text{MSE} = 82.08$. There were no main effects or interactions with the order factor. Planned comparisons showed the number of tones correctly identified in both the animacy and syllable DA conditions differed significantly from the full attention baseline condition, $F (1, 20) = 169.17, \text{MSE} = 102.69$. 
and $F(1, 20) = 100.26, \text{MSE} = 226.79$, respectively. The number of tones identified in the animacy versus syllable DA condition did not significantly different.

Table 2

Experiment 1 - Number of Correct Responses, Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Correct response</th>
<th>Reaction time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Baseline</td>
<td>102.91</td>
<td>20.00</td>
</tr>
<tr>
<td>DA man-made</td>
<td>74.14</td>
<td>16.60</td>
</tr>
<tr>
<td>DA syllable</td>
<td>70.00</td>
<td>19.71</td>
</tr>
</tbody>
</table>

Note. DA = divided attention

The mean RT to identify tones is shown for correct responses only (see Table 2). An outlier analysis eliminated RTs greater or lesser than two standard deviations from the mean for each participant in each condition. A within participant ANOVA revealed a main effect of condition $F(2, 40) = 28.64, \text{MSE} = 9537.11$. There were no significant main effects or interactions with the order factor.

The mean RT in both the animacy and syllable DA condition differed significantly from the mean in the baseline condition, $F(1, 20) = 58.31, \text{MSE} = 12819.02$ and $F(1, 20) = 34.77, \text{MSE} = 25466.43$, respectively. The difference in RT between the animacy and syllable DA condition was not significant, $F(1, 20) = 0.31$, suggesting the two distracting tasks make similar resource demands.
Discussion

Even though the memory load component of the distracting task was minimal, large interference effects were still observed under DA at retrieval. The magnitude of these effects was similar to those reported by Fernandes and Moscovitch (2000), where a verbal running recognition task and a word-monitoring distracting task led to an approximate 30% decline in memory performance, from full to DA conditions at retrieval. These effects are substantially larger than those reported by Baddeley et al. (1984), Craik et al. (1996), Naveh-Benjamin et al. (1998), and Anderson et al. (1998), but they used distracting tasks that involved non-verbal materials. These results suggest that word retrieval during recall can be impaired significantly by a concurrent task that also uses verbal material, irrespective of its memory load. Interference does not arise from competition for memory-specific systems.

These findings are consistent with the hypothesis derived from our neuropsychological model, that successful retrieval requires accessing a verbal representational system and that DA effects at retrieval arise when such a system is simultaneously required for another task (Fernandes & Moscovitch, 2000). Because the semantic and phonemic concurrent tasks produced equivalent interference effects, I conclude that competition may occur at a pre-semantic level, perhaps for phonemic or word-form representations. This hypothesis is evaluated further in Experiments 2 and 3.

I found that performance on the animacy and syllable distracting tasks was significantly affected in the dual-task conditions. The magnitude of interference on the animacy and syllable distracting tasks was consistent with that obtained in studies that
used non-verbal distracting tasks, even though I observed larger effects on memory performance. As originally suggested by Craik et al. (1996) and Johnston et al. (1970), these results show that the retrieval process demands substantial general processing resources, as indexed by the poorer performance on both distracting tasks under DA conditions, and does not operate automatically as Baddeley et al. (1984) claimed. These results are also in line with the suggestion that establishing and maintaining retrieval mode, and monitoring output, may be the resource-demanding aspect of retrieval (Fernandes & Moscovitch, 2000).

A direct analysis of task difficulty (independent of performance under DA with retrieval) showed that both the animacy and syllable distracting tasks had similar effects on the number of tones identified and RT on the auditory CRT task. Moreover the accuracy rates in dual-task conditions with the auditory CRT task were similar. This suggests that the two distracting tasks were equally difficult and resource demanding.

It should be noted that analysis of baseline RT to respond to each distracting task showed longer RTs for the syllable task, and that the percent increase in RT, from single to DA conditions with retrieval, was larger for the animacy task. Thus there is also a suggestion of a task-specific cost in that RT on the animacy task was disproportionately affected by DA. Because response speed was not emphasized in the instructions, RT to respond on the distracting task may not be as sensitive a measure as the auditory CRT task, which I chose explicitly to compare resource requirements for the distracting tasks (as in Fernandes & Moscovitch, 2000). These results are consistent with the claim that distracting task costs, under DA conditions with retrieval, are incurred regardless of
material used in the distracting task (Fernandes & Moscovitch, 2000), though there also may be a process-specific component affecting the size of the distracting task interference effect.

Overall, the animacy and syllable distracting tasks produced similarly large interference effects on memory, suffered to a similar degree when performed in dual conditions with retrieval, and did not differ in their resource demands. Because the resource demands of the distracting tasks were equivalent, a possible interpretation of the finding is that retrieval interference depends on the resource demands of the distracting task. I do not endorse this view, and instead favour a material-specific over a resource-competition account of retrieval interference. Even though the digit- and word-monitoring tasks used in my previous work (Fernandes & Moscovitch, 2000) were more demanding than either of the tasks used in Experiment 1, interference effects comparable in size to those in this experiment were obtained, only in the word-monitoring DA condition, supporting a material-specific interpretation. This issue is explored further in subsequent experiments.

Experiment 2

Introduction

The common factor across all experiments in which large interference effects from DA at retrieval were found (in Fernandes & Moscovitch, 2000, as well Experiment 1 of the present thesis), is that the distracting task involved verbal material. In the next experiment, I investigated what aspect of the words in the distracting task is responsible
for producing the unusually large effect. I ask whether it is the semantic processing or the phonological processing of word-forms that underlies interference at retrieval.

To address this question I compared the interference effect on memory produced from two different DA conditions at retrieval. In one, the distracting task retained a semantic component, but had no word-form, and in the other, the distracting task retained a word-form, that required phonological processing, but had no semantic component. One of the distracting tasks required participants to identify line-drawings representing man-made objects, among line drawings of living and man-made items, whereas the other required them to identify 2-syllable nonsense-words, among 1-, 2-, and 3-syllable pronounceable nonsense-words.

Recall that Experiment 1 showed the level of processing required in the distracting task did not influence the size of the interference effect. This led me to suggest that competition at a pre-semantic level, perhaps due to processing of word-forms, is responsible for the large interference effects on memory. If this proposal is correct, then a distracting task that involves phonological processing of word-like material, without semantics, should still impair retrieval. Along the same lines, a distracting task that consists of picture material (no direct word-form), and requires semantic processing, should produce much less interference with retrieval.

As in Experiment 1, I also considered changes in accuracy rate on each distracting task, performed singly and concurrently with retrieval. I expected significant declines in performance under dual-task conditions since retrieval is a resource-demanding process (Craik et al., 1996; Johnston et al., 1970), in that resources are needed to establish and
maintain retrieval mode, and monitor output (Fernandes & Moscovitch, 2000).

Furthermore, because the nonsense-word and picture tasks involved different materials, I also tested the claim that distracting task costs are incurred, under DA conditions with retrieval, regardless of material used in the distracting task (Fernandes & Moscovitch, 2000).

Because I was examining whether the picture-animacy and nonsense-word distracting tasks produced similar amounts of interference on memory, I wanted to ensure that any differences were not due to differential resource demands. As in Experiment 1, I assessed resource demands by comparing performance on each distracting task performed concurrently with the auditory CRT task. Again, the 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 a greater resource requirement. For consistency with Experiment 1, I also analyzed RT to respond for each distracting task, performed singly and in dual-task conditions with retrieval.

Method

Participants

Participants were 242 naïve undergraduate students at the University of Toronto who received $10.00 for their participation. All participants claimed to be native English speakers, and to have normal or corrected to normal vision and hearing.

Overview of experiment

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2 Data from three participants were excluded from Experiment 2 because the number of words they recalled in the full attention experimental condition was 4 words or less. Data from one participant were excluded because they misunderstood task instructions. Additional participants were tested in their place.
Experiment 2 was identical to Experiment 1 except that the word-based animacy and syllable distracting tasks were replaced by a task that required animacy decisions about pictures, and another task that required syllable decisions about pronounceable nonsense-words.

**Materials**

**Target recall task.** Stimuli for the target memory tasks were identical to those used in Experiment 1.

**Distracting tasks.**

**Picture-animacy decisions.** Stimuli consisted of 220 black line drawings from Snodgrass and Vanderwart (1980), presented on a white background. Each picture was 170 X 170 pixels in size. Four 50-picture lists, and one 20-picture list, were created such that half of the pictures represented man-made objects and the other half represented animals.

**Nonsense-word syllable decisions.** 220 pronounceable nonsense-words were created by changing 1-3 letters from words used in the syllable or animacy distracting task described in Experiment 1. Letters were changed such that the newly created nonsense-word was pronounceable. A research assistant and myself verified the number of syllables in each word when read aloud. Four lists of 50 nonsense-words, and one list of 20 nonsense-words were constructed. Each of these lists consisted of one, two and three syllable nonsense-words; half of the nonsense-words for each list had two syllables, and the rest had one or three syllables.
For both distracting tasks, stimuli were presented visually in the center of a computer screen at a rate of one item every 2 seconds. For the picture-animacy task, participants indicated if the presented picture represented a man-made object by making a keypress using their dominant writing hand. For the nonsense-word syllable task, participants indicated if the presented nonsense-word had two syllables by making a keypress.

**Arithmetic task.** As in Experiment 1, the study phase for the target memory task was always followed immediately by an arithmetic task to eliminate recency (as in Craik et al., 1996).

**Procedure**

**Practice session.** Participants were tested individually. As in Experiment 1, participants performed the target memory task under full attention, followed by a practice session on the picture-animacy and nonsense-word syllable task. The order of practice block for the distracting tasks was counterbalanced.

**Experimental sessions.** The procedure was identical to that described for Experiment 1, except that the animacy and syllable tasks were replaced by the picture-animacy and nonsense-word syllable distracting tasks.

**Comparing difficulty of the distracting tasks.**

As in the first Experiment, I wished to determine whether the distracting tasks were equally difficult and/or resource demanding. Again I considered each participant’s performance on the auditory CRT task, performed alone and in dual-task conditions with each of the distracting tasks. The method was the same as in Experiment 1 except that the
Results

Target memory task. The nonsense-word syllable task interfered substantially with free recall performance. However, free recall did not decline as much when the picture-animacy task was performed concurrently at retrieval. The means for each condition are presented in Table 3. The data were analyzed in a two between (order of experimental condition and order of single-task measure for the picture and nonsense-word task) and one within (experimental condition) ANOVA. There were no significant main effects or interactions with the order factors on free recall performance. Results were significant at p < .001 unless otherwise noted.

There was a main effect of experimental condition $F (2, 46) = 18.89$, $MSE = 1.94$. For each DA condition, the number of words recalled was significantly lower than the full attention baseline condition, $F (1, 23) = 11.74$, $MSE = 4.35$, $p < .01$ and $F (1, 23) = 30.9$, $MSE = 4.69$ for the picture and nonsense-word conditions respectively. The mean number of words recalled in the picture DA condition differed significantly from the mean nonsense-word DA condition, $F (1, 23) = 9.2$, $MSE = 2.61$, $p < .01$. The difference in mean percentage decline in memory (ratio of performance for each participant under full and DA conditions), between the picture-animacy and nonsense-word DA conditions, was significant, $t (22) = -2.89$, $p < .01$. 

animacy and syllable tasks were replaced by the picture-animacy and nonsense-word syllable distracting tasks.
### Table 3

Experiment 2 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Decline From Single to Dual-task Condition For Each Measure

<table>
<thead>
<tr>
<th>Measure and condition</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target memory task</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words recalled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Attention</td>
<td>7.54</td>
<td>2.23</td>
</tr>
<tr>
<td>DA picture-animacy</td>
<td>6.08</td>
<td>1.93</td>
</tr>
<tr>
<td>DA nonsense-word</td>
<td>5.08</td>
<td>2.06</td>
</tr>
<tr>
<td>Percentage Decline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA picture-animacy</td>
<td>16.00</td>
<td>24.60</td>
</tr>
<tr>
<td>DA nonsense-word</td>
<td>30.68</td>
<td>26.03</td>
</tr>
<tr>
<td><strong>Distracting task</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy rate</td>
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<td></td>
</tr>
<tr>
<td>Baseline picture-animacy</td>
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<td>.14</td>
</tr>
<tr>
<td>DA picture-animacy</td>
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<td>.14</td>
</tr>
<tr>
<td>Baseline nonsense-word</td>
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<td>.17</td>
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<tr>
<td>DA nonsense-word</td>
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<td>Filler</td>
<td>.93</td>
<td>.15</td>
</tr>
<tr>
<td>Percentage decline in accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA picture-animacy</td>
<td>6.21</td>
<td>32.12</td>
</tr>
<tr>
<td>DA nonsense-word</td>
<td>31.74</td>
<td>17.40</td>
</tr>
<tr>
<td>Reaction time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline picture-animacy</td>
<td>653.42</td>
<td>112.35</td>
</tr>
<tr>
<td>DA picture-animacy</td>
<td>817.00</td>
<td>160.51</td>
</tr>
<tr>
<td>Baseline nonsense-word</td>
<td>1073.54</td>
<td>195.64</td>
</tr>
<tr>
<td>DA nonsense-word</td>
<td>1062.29</td>
<td>198.68</td>
</tr>
<tr>
<td>Percentage increase in reaction time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA picture-animacy</td>
<td>18.45</td>
<td>14.61</td>
</tr>
<tr>
<td>DA nonsense-word</td>
<td>-0.02</td>
<td>17.02</td>
</tr>
</tbody>
</table>

**Note:** DA = divided attention
Following each DA condition, the participants were given the chance to recall words from the target task under full attention. As in the first Experiment, few participants recalled any additional words. The mean number of additional words recalled after the 'picture-animacy' and 'nonsense-word syllable' DA conditions was only 0.42 (S.D. = .65) and 0.67 (S.D. = 1.09) respectively.

**Distracting tasks**

**Accuracy rate.**

Accuracy rates (calculated as #hits/15 - # false alarms/15) on the nonsense-word and picture-animacy task, under DA conditions with free recall, were worse than single-task performance. The percentage decline in accuracy rate, from single to dual-task conditions, was much larger on the nonsense-word than picture-animacy task. The data were analyzed in a two between (order of experimental condition and order of single-task measure for the picture and nonsense-word task) and one within (experimental condition) ANOVA. There was a main effect of experimental condition, $F (3, 69) = 40.10$, $MSE = 0.02$. Mean accuracy rates for each task, in each condition, are presented in Table 3. There were no significant main effects or interactions with the order factors on distracting task performance.

Accuracy rates on the picture and nonsense-word distracting tasks, under DA conditions with free recall, were worse than single-task performance. ($F (1, 23) = 7.33$, $MSE = 0.03$, $p < .05$, and $F (1, 23) = 70.79$, $MSE = .02$, respectively). Percentage decline in accuracy rate, from single to dual task performance, was significantly larger on the nonsense-word than picture-animacy task ($t (22) = -3.02$, $p < .01$).
**Reaction Time:**

The mean RT to make a response, for each distracting task, in the baseline and dual-task condition with retrieval is noted in Table 3. The baseline RT was significantly longer for the nonsense-word than picture-animacy distracting task ($t(22) = -11.47$). The percentage increase in RT, from baseline to dual-task conditions was significantly greater for the picture-animacy than nonsense-word task ($t(22) = 4.34$).

The correlation between RT on the distracting task, and memory interference under each DA condition was non-significant.

**Auditory CRT**

**Distracting task.** The accuracy rate was higher on the picture than nonsense-word distracting task, when each was performed concurrently with the auditory CRT task, $t(23) = 4.42$. There was no effect of task order on accuracy rates. The mean accuracy rates on the picture-animacy and nonsense-word tasks, were $.67$ (S.D. = $.16$) and $.48$ (S.D. = $.18$) respectively.

**CRT tone task.** The difference in the number of tones correctly identified in the picture and nonsense-word DA conditions was not significant. The mean number of correct responses for each condition is presented in Table 4. A within participant ANOVA revealed a main effect of condition $F(2, 46) = 107.95$, **MSE** = 60.17. There were no main effects or interactions with the order factor. Planned comparisons showed the number of tones correctly identified in the picture and nonsense-word DA conditions differed significantly from the full attention baseline condition, $F(1, 23) = 116.42$, **MSE** = 152.61 and $F(1, 23) = 129.27$, **MSE** = 162.94 respectively.
Table 4

Experiment 2 - Number of Correct Responses, Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>91.58</td>
<td>19.45</td>
<td>840.26</td>
<td>187.67</td>
</tr>
<tr>
<td>DA picture-animacy</td>
<td>64.38</td>
<td>17.91</td>
<td>961.54</td>
<td>168.69</td>
</tr>
<tr>
<td>DA nonsense-word</td>
<td>61.96</td>
<td>16.35</td>
<td>1046.34</td>
<td>217.99</td>
</tr>
</tbody>
</table>

The mean RT to identify tones is shown for correct responses only (see Table 4). An outlier analysis eliminated RTs greater or lesser than two standard deviations from the mean for each participant in each condition. A within participant ANOVA revealed a main effect of condition $F(2, 46) = 18.58$, $MSE = 13855.26$. There were no significant main effects or interactions with the order factor.

The mean RT in both the picture and nonsense-word DA condition differed significantly from the mean in the baseline condition, $F(1, 23) = 16.20$, $MSE = 21787.87$, $p < .01$, and $F(1, 23) = 21.00$, $MSE = 48523.42$, respectively. The difference in RT between the two DA conditions was significant, $F(1, 23) = 13.46$, $MSE = 12820.27$, $p < .01$.

Discussion

A large interference effect on memory performance, comparable in size to that found in Experiment 1, was observed under DA at retrieval using the nonsense-word syllable task. The picture-animacy task, performed concurrently with retrieval, produced a
much smaller effect on memory though it was still significant. These results suggest that phonological processing of word-like material in a distracting task is sufficient to impair the retrieval process. In contrast, semantic processing of items in the distracting task does not exert nearly as great an interference effect at retrieval. These results are consistent with the suggestion from Experiment 1 that the primary locus of interference under DA at retrieval occurs at a pre-semantic level. That is, competition at the level of word-form representations is sufficient to interfere with retrieval. These findings are also consistent with the hypothesis that DA effects at retrieval occur primarily due to competition for a representational system (Fernandes & Moscovitch, 2000), though they do not exclude other sources of interference.

It should be noted that single-task performance of the nonsense-word task, as well as the percentage decline in accuracy rate from single to dual-task conditions is comparable to that observed for the animacy and syllable distracting tasks from Experiment 1. Moreover, the relative increase in RT to identify tones on the auditory CRT task, from single to dual-task conditions, is similar in the nonsense-word task to distracting tasks in Experiment 1. This argues against the possibility that the nonsense-word task created interference at retrieval due to increased task-difficulty, or resource requirements.

Even though the picture-animacy distracting task did not produce as large of an interference effect on memory, it was nonetheless significant. My interpretation is that this result argues against the conclusion that memory interference occurs solely due to competition at the level of word-form representations. Semantic processing in a
distracting task that has no word-form component also disrupts memory retrieval, though to a lesser degree. Another possible interpretation is that the pictures may on occasion activate the word-form system. Because this does not occur on all trials, the interference effect is diminished.

It should also be noted that the picture-animacy task was shown, on multiple measures, to be easier to perform than the nonsense-word task. There was a much smaller decrement in accuracy rate, from single to dual-task conditions, on the picture-animacy task than nonsense-word task. Also, when performed under dual-task conditions with the auditory CRT task, the accuracy rate on the picture-animacy task was much higher, and the RT much shorter than in the nonsense-word task. It is possible that had the picture-task been more difficult to perform, or more resource-demanding, larger interference effects on memory would have been observed. Thus semantic processing in a distracting task might contribute more to interference effects on memory retrieval than Experiment 2 would suggest. I explore this possibility in Experiment 3.

Examination of distracting task costs shows the expected decline in accuracy rate from single to dual-task conditions for both the picture-animacy and nonsense-word task. Thus, as previous work suggests (Craik et al., 1996), the retrieval process is resource demanding as indexed by poorer performance when distraction is concurrent with retrieval. The size of the decrement in accuracy on the nonsense-word task is similar to that observed in previous studies of DA at retrieval and to that observed with the distracting tasks from Experiment 1. The decrement on the picture-animacy task is smaller.
Fernandes and Moscovitch (2000) suggested that distracting task costs should not differ depending on the material used in the distracting task, yet they did in this experiment. However, just as the issue of task difficulty blurs interpretation of the effects of DA on memory, task difficulty likely played a role in modulating the size of distracting task decrements. The results from the auditory CRT task showed that picture-animacy was much easier to perform than the nonsense-word task. This possibly accounts for the smaller decrement in distracting task performance under DA conditions with retrieval. Nonetheless, the significant decrement observed in both distracting tasks suggests that the major source of interference, of the memory task on the distracters, is competition for general resources rather than for material-specific systems or processes. I discuss this issue further in the General Discussion of Chapter 2, after considering distracting task costs across all three experiments in this section.

Experiment 3

Introduction

Even though the picture-animacy distracting task was much easier than the nonsense-word task, the effect it produced on memory was significant. These results prevent me from concluding that memory interference occurs exclusively from competition at the level of phonological or word-form representations. Semantic processing in the picture-animacy task obviously has some effect on memory retrieval, though Experiment 2 does not allow me to determine the extent. The purpose of the present experiment was to examine whether the magnitude of the effect of a picture-based distracting task on memory would increase, and approach that observed with the
nonsense-word task, when the two were equated for level of difficulty and resource demands. In Experiment 3, I created a new picture-based distracting task, which required participants to make size decisions about pictures rather than animacy decisions. The task involved identifying line-drawings that represented objects in the real world that were bigger than an average computer monitor. A pilot study showed that the size judgement task was more difficult to perform than the picture-animacy task.

In this experiment I also included the nonsense-word DA condition in an attempt to replicate the results from that condition in Experiment 2. The corollary prediction from Fernandes and Moscovitch (2000) is that if interference effects at retrieval are material-specific, then even a difficult picture-based distracting task should produce less interference on word retrieval than the nonsense-word syllable task.

In addition, creating a more difficult picture-based distracting task allowed me to re-examine the claim that decrements in distracting task accuracy rate, performed under DA conditions with retrieval, depend more on general resource-competition between the memory and distracting task than on competition for material-specific representational systems.

As in Experiments 1 and 2, the auditory CRT task was used to compare resource-demands of the distracting tasks. The RT and number of correct responses on the auditory CRT task were recorded and analyzed, and taken as a measure of how demanding each distracting task was, with longer RTs indicating a greater resource demand.
Method

Participants

Participants were 24 naive undergraduate students at the University of Toronto who received $10.00 for their participation. All participants claimed to be native English speakers, and to have normal or corrected to normal vision and hearing.

Overview of experiment

Experiment 3 was identical to Experiment 2 except that the picture-animacy distracting task was replaced by a task that required size decisions to pictures.

Materials

Target recall task. Stimuli for the target memory tasks were identical to those used in Experiments 1 and 2.

Distracting tasks.

Picture-size decisions. Stimuli consisted of 220 Snodgrass and Vanderwart (1980) black line drawings, presented on a white background. Each picture was 170 X 170 pixels. Four 50-picture lists, and one 20-picture list were created. Half of the pictures in each list represented objects that in the real world were bigger than a computer monitor in size, and the other half represented objects smaller than a monitor in size.

Nonsense-word syllable decisions. The same materials were used as in Experiment 2.

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3 Data from several participants were excluded from Experiment 3. Three participants had accuracy rates of zero, or near zero on the 'nonsense-word' task under DA conditions. Seven participants recalled 4 words or less in the full attention condition, and one participant claimed her memory went blank in experimental conditions. Additional participants were tested in their place.
For both distracting tasks, stimuli were presented visually on the computer screen at a rate of one item every 2 seconds. For the picture-size task, participants indicated if the presented picture represented an object in the real world that was bigger than a computer monitor in size, by making a keypress using their dominant writing hand. For the nonsense-word syllable task, participants indicated if the presented nonsense-word had two syllables by making a keypress.

Arithmetic task. As in Experiment 1 and 2, the study phase for the target memory task was always followed immediately by an arithmetic task to eliminate recency (as in Craik et al., 1996).

Procedure

Practice session. Participants were tested individually. As in Experiment 2, participants performed the target memory task under full attention, followed by a practice session on the picture-size and nonsense-word syllable task. The order of practice block for the distracting tasks was counterbalanced.

Experimental sessions. The procedure was identical to that described for Experiment 1 (and 2), except that the animacy and syllable tasks were replaced by the picture-size and nonsense-word syllable distracting tasks.

Comparing difficulty of the distracting tasks.

As in Experiments 1 and 2, I wished to determine whether the distracting tasks were equally resource demanding. These results were especially important given that the aim of Experiment 3 was to create a picture-based distracting task that was comparable in resource demands to the nonsense-word task. I considered each participant's performance
on the auditory CRT task, performed alone and in dual-task conditions with each of the distracting tasks. The method was the same as in Experiments 1 and 2 except that the animacy and syllable tasks were replaced by the picture-size and nonsense-word syllable distracting tasks.

Results

Target memory task. Once again, the nonsense-word syllable task interfered substantially with free recall performance, while interference was not as great when the picture-size task was performed concurrently at retrieval. The means for each condition are presented in Table 5. The data were analyzed in a two between (order of experimental condition and order of single-task measure for the picture and nonsense-word task) and one within (experimental condition) ANOVA. Results were significant at $p < .001$ unless otherwise noted.

There were no significant main effects with the order factors on free recall performance, though the Order X Condition interaction was significant $F(10, 36) = 2.90$, $MSE = 2.05$, $p < .01$. For all orders, the number of words recalled in the full attention condition exceeded that in the nonsense-word DA condition. For two of the six orders (in which the nonsense-word DA condition was given as the 1st or 2nd experimental condition), the number of words recalled in the nonsense-word DA condition exceeded that in the picture-size DA condition by 1 to 1.75 words. For another one of the orders, the number of words recalled in the nonsense-word DA condition was 0.5 above that in the picture-size DA condition. For the remaining three orders, participants recalled on average 1.5 to 3.5 more words in the picture-size than nonsense-word DA condition.
There was no particular order of experimental conditions that could account for the Order X Condition interaction; the interaction appears to stem from the high variability in number of words recalled in the nonsense-word DA condition.

There was a main effect of experimental condition $F (2, 46) = 13.66$, $\text{MSE} = 2.89$. For each DA conditions, the number of words recalled was significantly lower than the full attention baseline condition, $F (1, 23) = 13.58$, $\text{MSE} = 5.41$, $p < .01$ and $F (1, 23) = 28.75$, $\text{MSE} = 5.22$ for the picture-size and nonsense-word conditions, respectively. I conducted one-tailed t-tests to compare the two DA conditions to each other since I had a directional hypothesis. The difference in number of words recalled in the picture-size compared to nonsense-word DA condition approached, but did not reach statistical significance, $t (22) = 1.42$, $p = 0.11$. The difference in percentage decline in memory (from full attention to DA conditions), for the picture-size and nonsense-word DA conditions, was significant, $t (22) = -1.75$, $p < .05$. 

Table 5

Experiment 3 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Decline From Single to Dual-task Condition For Each Measure

<table>
<thead>
<tr>
<th>Measure and condition</th>
<th>M</th>
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</thead>
<tbody>
<tr>
<td><strong>Target memory task</strong></td>
<td></td>
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<tr>
<td>Words recalled</td>
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<td></td>
</tr>
<tr>
<td>Full Attention</td>
<td>9.08</td>
<td>2.69</td>
</tr>
<tr>
<td>DA picture-size</td>
<td>7.33</td>
<td>2.46</td>
</tr>
<tr>
<td>DA nonsense-word</td>
<td>6.58</td>
<td>3.23</td>
</tr>
<tr>
<td>Percentage Decline</td>
<td></td>
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<tr>
<td>DA picture-size</td>
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<td>Accuracy rate</td>
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<td>Baseline picture-size</td>
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<td>.90</td>
<td>.16</td>
</tr>
<tr>
<td>Percentage decline in accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA picture-size</td>
<td>19.95</td>
<td>16.07</td>
</tr>
<tr>
<td>DA nonsense-word</td>
<td>32.82</td>
<td>21.22</td>
</tr>
<tr>
<td>Reaction time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline picture-size</td>
<td>693.38</td>
<td>87.73</td>
</tr>
<tr>
<td>DA picture-size</td>
<td>796.08</td>
<td>83.26</td>
</tr>
<tr>
<td>Baseline nonsense-word</td>
<td>1018.21</td>
<td>180.24</td>
</tr>
<tr>
<td>DA nonsense-word</td>
<td>1129.83</td>
<td>183.62</td>
</tr>
<tr>
<td>Percentage increase in reaction time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA picture-size</td>
<td>12.63</td>
<td>9.06</td>
</tr>
<tr>
<td>DA nonsense-word</td>
<td>8.82</td>
<td>15.65</td>
</tr>
</tbody>
</table>

Note: DA = divided attention
Following each DA condition, the participants were given the chance to recall words from the target task under full attention. As in the other Experiments, few participants recalled any additional words. The mean number of additional words recalled after the picture-size and nonsense-word syllable DA conditions was .38 (\(S.D. = .58\)) and 0.89 (\(S.D. = 1.08\)) respectively. These were not significantly different from each other.

**Distracting tasks**

**Accuracy rate.**

Accuracy rates (calculated as \#hits/15 - \# false alarms/15) on the nonsense-word and picture-size tasks, under DA conditions with free recall, were worse than single-task performance. The percentage decline in accuracy rate, from single to dual-task conditions, was larger on the nonsense-word than picture-size task. The data were analyzed in a two between (order of experimental condition and order of single-task measure for the picture and nonsense-word task) and one within (experimental condition) ANOVA. There was a main effect of experimental condition, \(F (3, 69) = 30.03, \text{MSE} = 0.02\). Mean accuracy rates for each task, in each condition, are presented in Table 5. There were no significant main effects or interactions with the order factors on distracting task performance.

Accuracy rates on the picture and nonsense-word distracting tasks, under DA conditions with free recall, were worse than single-task performance. \(F (1, 23) = 36.38, \text{MSE} = 0.02, \text{and } F (1, 23) = 51.54, \text{MSE} = .04\), respectively). Percentage decline in accuracy, from single to dual task performance, was significantly larger on the nonsense-word than picture-size task \(t (22) = -2.34, p < .05\).
The reaction time to respond on each distracting task, in the baseline and dual-task condition with retrieval is noted in Table 5. The baseline RT was significantly longer for the nonsense-word than picture-size distracting task (t (22) = -7.61). The percentage increase in RT, from baseline to dual-task conditions did not differ significantly for the picture-size and nonsense-word task. (t (22) = 0.93, p > .36).

The correlation between RT on the distracting task, and memory interference under each DA condition was non-significant.

Auditory CRT

Distracting task. The accuracy rate for both of the distracting tasks suffered to a similar degree when the auditory CRT task was performed concurrently. The mean accuracy rates on the picture-size and nonsense-word tasks, were .54 (S.D. = .15) and .55 (S.D. = .29) respectively. There was a marginally significant effect of task order on accuracy rate for the picture-size task F (1,22) = 6.90, MSE = .13, p<.05, with those performing the task as the first dual-task condition with the CRT task, versus second, obtaining a mean accuracy of .47 (S.D. = .13) and .63 (S.D. = .29) respectively. There was no effect of task order on accuracy rate for the nonsense-word task.

CRT tone task. The difference in the number of tones correctly identified in the picture-size and nonsense-word DA conditions was not significant. The mean number of correct responses for each condition is presented in Table 6. A within participant ANOVA revealed a main effect of condition F (2, 46) = 72.76, MSE = 95.86. There were no main effects of the order factor. Planned comparisons showed the number of tones correctly identified in the picture-size and nonsense-word DA conditions differed
significantly from the full attention baseline condition, $F(1, 23) = 77.06$, $\text{MSE} = 252.96$ and $F(1, 23) = 117.40$, $\text{MSE} = 189.65$ respectively. The number of tones identified in the picture-size versus nonsense-word DA condition was not significantly different.

Table 6

<table>
<thead>
<tr>
<th>Condition</th>
<th>Correct response</th>
<th>Reaction time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Baseline</td>
<td>107.58</td>
<td>23.06</td>
</tr>
<tr>
<td>DA picture-size</td>
<td>79.08</td>
<td>20.46</td>
</tr>
<tr>
<td>DA nonsense-word</td>
<td>77.13</td>
<td>20.58</td>
</tr>
</tbody>
</table>

The mean RT to identify tones is shown for correct responses only (see Table 6). An outlier analysis eliminated RTs greater or lesser than two standard deviations from the mean for each participant in each condition. A within participant ANOVA revealed a main effect of condition $F(2, 46) = 43.15$, $\text{MSE} = 8505.95$. There were no significant main effects or interactions with the order factor.

The mean RT in both the picture-size and nonsense-word DA condition differed significantly from the mean in the baseline condition, $F(1, 23) = 54.84$, $\text{MSE} = 20652.66$, and $F(1, 23) = 61.99$, $\text{MSE} = 17239.96$ respectively. The difference in RT between the two DA conditions was not significantly different.

Comparison of Experiment 2 and 3
In order to determine how the increase in task difficulty modulated the interference effect of the picture-based distracting task on memory, and vice versa, I re-analyzed the data from Experiments 2 and 3, using an ANOVA with Experiment as a between participant factor. I also wanted to determine whether the interference effect on memory and the distracting task was similar in the nonsense-word DA condition, across Experiments 2 and 3. A separate analysis was carried out for the percentage decline in recall and distracting task accuracy.

The main effect of Experiment on percent decline in memory task performance was not significant, $F(1, 46) = 0.01$. The main effect of Condition was significant, $F(1, 46) = 9.94$, MSE = 0.04, but the Condition X Experiment interaction was not, $F(1, 46) = 0.16$. Planned t-tests showed that the percentage decline in memory performance did not differ in the picture-animacy and picture-size DA conditions, $t(46) = -0.15$. Similarly, the percentage decline in memory did not differ in the nonsense-word DA condition, across Experiments 2 and 3, $t(46) = 0.29$.

The main effect of Experiment on percentage decline in distracting task performance, was not significant, $F(1, 46) = 3.20$. The main effect of Condition was significant, $F(1, 46) = 14.52$, MSE = 0.06, but the Condition X Experiment interaction was not, $F(1, 46) = 1.58$. Planned t-tests showed that the percentage decline in distracting task performance did not differ in the picture-animacy and picture-size DA conditions, though the difference approached significance, $t(34) = -1.87$, $p = .07$. The percentage decline in distracting task performance did not differ in the nonsense-word DA condition, across Experiments 2 and 3, $t(46) = -0.19$. 
Discussion

A large interference effect on memory performance was observed under DA at retrieval using the nonsense-word distracting task. The effect was comparable in size to that found in Experiment 1, and replicated the results from the nonsense-word DA condition of Experiment 2. The picture-size task produced a smaller effect on memory though it was still significant.

Results from the auditory CRT task show that the picture-size and nonsense-word distracting tasks were equally resource-demanding. The number of tones identified in each dual-task condition, and the RT on the auditory CRT task did not differ significantly. Moreover, the accuracy rates in dual-task conditions with the auditory CRT task were similar for the picture-size and nonsense-word distracting tasks.

Thus, despite making the picture-based distracting task more resource demanding, it did not produce a larger effect on memory than the picture-animacy task from Experiment 2. As in Experiment 2, the nonsense-word DA condition produced the larger interference effect, suggesting that orthographic or phonological processing of word-like material in a distracting task is sufficient to impair the retrieval process.

The nonsense-word DA condition produced a significantly larger percentage decline in memory performance (from full attention) than the picture-size DA condition, though in absolute terms (mean number of words recalled in each DA condition), the difference between them did not reach significance. Comparison between Experiment 2 and 3 shows that the picture-size task did not produce a larger interference effect than the
picture-animacy task, and that the nonsense-word task in both experiments produced effects of very similar size.

The larger interference effect produced by the nonsense-word compared to picture-size distracting task suggests that the primary locus of interference under DA at retrieval occurs at a pre-semantic level. This does not, however, rule out the possibility that there may be other ways of interfering with memory retrieval. I discuss this issue in more detail in the General Discussion of Chapter 2.

In all of my experiments I analyzed response RT on the distracting tasks since I initially believed it could provide an indirect measure of resource-requirements for each distracting task. However, in Experiment 1, the baseline RT on the animacy and syllable distracting tasks differed, as did the percentage increase in RT under DA conditions, yet these tasks produced similar amounts of interference on memory. This suggests that differences in response RTs, on the distractor tasks, are not related to the amount of interference produced by these tests on memory under DA conditions. Moreover, the results of the analysis of response RT were often in the opposite direction to those found on the auditory CRT task, possibly because I emphasized accuracy in responses on the distracting tasks, and did not explicitly inform participants that RT was also being measured. Thus, RT cannot be considered as sensitive a measure of task-difficulty and/or resource demands as the auditory CRT task, which was conducted explicitly to evaluate this issue. Also, the auditory CRT task measures performance of each distracting task independent of its effects under DA with memory retrieval. As such, I believe it provides a more accurate measure of task difficulty and/or resource requirements for each
distracting task.

Even though the picture-size and nonsense-word tasks were shown (on the auditory CRT task) to be equally difficult or resource demanding, the magnitude of interference observed on each task’s accuracy rate under dual-task conditions with retrieval were different. DA led to a 20% and 33% decline in distracting task accuracy rate for each task, respectively. These both represent significant declines in distracting task performance, and thus support the idea that retrieval is resource demanding (Craik et al., 1996; Johnston et al., 1970). However, the difference in magnitude of the decrement to the distracting tasks suggests that in addition to general resource competition, there may be a material-specific component to the effect. This issue is addressed in the General Discussion of Chapter 2.

Overall, the nonsense-word distracting task produced large interference effects on memory, similar in magnitude to those observed in Experiment 1 and to those observed from verbal-based distracting tasks in Fernandes and Moscovitch (2000). Thus, phonological processing of word-forms, without semantic content, can significantly disrupt the retrieval process. An equally difficult picture-based distracting task produces significant, though smaller effects on memory, indicating that semantic processing plays a smaller role than word-form processing, in producing interference at retrieval. This suggests that even though semantic processing in a distracting task is capable of disrupting retrieval, it is not the key factor modulating the size of memory interference from DA at retrieval.
General Discussion of Chapter 2 Experiments

The present experiments document large interference effects on recall of a list of unrelated words, when a distracting task involving word, or word-like, material is performed concurrently. The magnitude of these effects are similar to those reported by Fernandes and Moscovitch (2000), where a verbal running recognition task and a word-monitoring distracting task led to an approximate 30% decline in memory performance, from full to DA conditions at retrieval. These results stand in contrast to other studies of verbal memory in which retrieval was performed concurrently with non-verbal distracting tasks, such as card-sorting (Baddeley et al., 1984), digit-monitoring (Fernandes and Moscovitch, 2000), or a visuo-spatial task (Craik et al., 1996; Naveh-Benjamin et al., 1998), which led to small interference effects on memory.

Recall Task Performance

This series of experiments was designed to investigate which aspect of verbal-based distracting tasks leads to large interference effects on memory, and in doing so provide insight into the resources, and underlying neural systems necessary for retrieval. I initially investigated whether it was necessary to have a memory component in the distracting task to produce interference. All of the verbal distracting tasks from Fernandes and Moscovitch (2000) had a memory load, which left open the possibility that interference effects could potentially be due to competition for memory structures rather than for a common, word-based representational system as they suggested.

In the first experiment, despite eliminating the memory component of the distracting task, I found that on-line word-based tasks such as animacy or syllable
judgements, performed concurrently with retrieval, produced large interference effects. Furthermore, these effects were not modulated by the level of processing required in the distracting task, whether semantic or phonological. This suggested that the word-form or phonological aspect of the words in the distracting task, rather than their semantic content, accounted for the large interference effect on memory.

Consistent with this suggestion, Experiments 2 and 3 showed that even a distracting task involving nonsense-words, that has no semantic content, produced comparably large effects on memory. On the other hand, a semantic distracting task involving pictures with no word-form component, produced a significant, but smaller, effect on memory (See Figure 1). Increasing the level of difficulty of the picture-based task, from Experiment 2 to Experiment 3, did not increase the size of the interference effect significantly. Thus, to have the largest effect on retrieval, the distracting task should engage word-form or phonological processes.
Figure 1. Mean percentage decline in free recall performance from full to divided attention (DA) for each condition in Experiment (Expt.) 1, 2, and 3.
Since the nonsense-word task, which did not have a semantic processing component, led to large interference effects on memory, semantic processing in a distracting task is not essential in disrupting memory retrieval. Consistent with this suggestion, the picture-animacy and picture-size tasks, performed concurrently with retrieval, produced significantly smaller declines in memory (16-17%), than the nonsense-word tasks (28-31%) in Experiments 2 and 3. Though smaller, these declines in memory from the picture tasks are nonetheless significant, suggesting that semantic processing or competition for general resources can also disrupt the retrieval process. Alternatively, because the pictures were line drawings of common objects, they may have accessed the name on some trials and led to interference effects at a phonological level.

It is possible that any distracting task that is resource-demanding disrupts the retrieval process somewhat, due to the added complexity of coordinating two tasks. The size of the interference effect produced by the picture-based tasks is not that different from what has been found in other studies that used non-verbal distracting tasks (Experiment 4 Fernandes & Moscovitch, 2000; Craik et al., 1996; Naveh-Benjamin, 1998, Anderson, et al., 1998). Thus non-verbal distracting tasks may produce small but reliable interference effects on memory retrieval for an altogether different reason than the large effects created from word-based distracting tasks. Perhaps some amount of attention is required for memory retrieval and is compromised by having to coordinate another task along with memory retrieval, leading to small yet significant effects of DA. Consistent with the neuropsychological model described in Chapter 1, ephory (reactivation of the memory trace) may still be automatic, but post-ephoric search and post-ephoric monitoring
processes may be compromised (see below):

**Distracting Task Performance**

Another important finding from this study is that accuracy rate on all of the distracting tasks suffered under DA conditions with retrieval. Thus, in agreement with Craik et al. (1996), Anderson et al. (1998) and Naveh-Benjamin et al. (1998), retrieval is not an automatic process, as it draws resources away from the distracting task under DA, leading to distracting task costs. In this series of experiments, the magnitude of the decrement in accuracy was variable across experiments. Figure 2 shows the percentage decline in accuracy for each task in each experiment.
Figure 2. Mean percentage decline in accuracy rate from single to divided-attention (DA) for each condition in Experiment (Expt.) 1, 2, and 3.
I attribute the very small decline in the picture-animacy task to the fact that it was shown on multiple measures to be less difficult and less resource-demanding than the other tasks in this study (see Experiment 2 Results and Discussion). Looking at the performance costs for the remaining distracting tasks, notice that the word-animacy task from Experiment 1 and the picture-size task from Experiment 3 show a relatively smaller decline in performance than the other tasks. The word-animacy task produced large effects on memory, similar in size to the syllable and nonsense-word distracting tasks, despite the fact that its accuracy rate was not as affected. The picture-size task produced small effects on memory, but its accuracy rate declined by the same amount as the word-animacy task, which produced larger effects on memory. These results suggest that distracting task costs can differ depending on the task used to divide attention during retrieval. However, material-specificity of the distracting task, performed concurrently with free recall, is not the factor producing this variability. If it were, the word-animacy and picture-size distracting tasks would have led to different amounts of decline, and not the same amount, as I have found.

Thus, if I consider performance costs associated with DA across all three experiments, these results support the claim that costs occur independently of material used in the distracting task (Fernandes & Moscovitch, 2000). Whether these costs are actually associated with the maintenance of retrieval mode and/or reflect general resource requirements remains to be determined. It is worthwhile to note that the largest effects on distracting task performance were observed when the distracting task required
phonological processing. This suggests that performance decrements, on the memory and 
distracting task, may be due to competition for phonological processing resources.

Persistent Interference Effects of DA at Retrieval

A curious finding across all of the experiments is that participants could not recall 
many additional words from the study list after the DA conditions were over. A similar 
finding was reported by Fernandes and Moscovitch (2000). They suggested that short-
term consolidation or cohesion (Moscovitch, 1995; Nadel & Moscovitch, 1997) may be 
disrupted by the concurrent activation of neocortical representations needed for the verbal 
memory and distracting task. Given that the nonsense-word task was also able to disrupt 
memories, even after the DA condition was complete, this suggests that the locus of the 
prolonged interference effect is based on access to phonological or orthographic codes, 
though the present experiments do not allow me to decide between these alternatives.

Conclusions

These experiments showed that under DA conditions with retrieval, distracting 
tasks need not have a memory or semantic processing component in order to create large 
interference effects with memory. This led me to suggest that large interference effects 
occur primarily due to competition at a pre-semantic level. Consistent with this 
suggestion, I found that a nonsense-word distracting task, that had no semantic content, 
produced large effects on memory. Thus, competition at the level of a word-form system 
is sufficient to produce large interference effects on free recall; whether competition is for 
orthographic or phonological representations cannot be determined from these 
experiments. An equally difficult picture-based distracting task produced significant
interference with memory retrieval, but the effect was smaller in magnitude than that produced by using words or nonsense words in the distracting task.

I also found that accuracy rate in the distracting task is always significantly affected when performed concurrently with retrieval. The magnitude of this interference varies for different distracting tasks, and is unrelated to success at retrieval. Furthermore, this variation cannot be accounted for by type of material used in the distracting task. It remains to be determined whether the costs to the distracting task are associated with the maintenance of retrieval mode (Fernandes & Moscovitch, 2000) and/or reflect general resource requirements for retrieval (Craik et al., 1996).

By showing that retrieval can be disrupted by performing a concurrent task, these results indicate that retrieval does not always occur obligatorily. Furthermore, these data suggest that this disruption occurs primarily when there is competition between the distracting and memory task for access to a word-form system which is needed to reactivate the memory trace, and to perform the distracting task.
Chapter 3

In this chapter, I examine whether a resource-based explanation can account better for the pattern of interference effects from dual-tasks at retrieval, than the neuropsychological model described in the previous 2 chapters. The work by Fernandes and Moscovitch (2000) suggested that performing a word-based task, concurrently with recall of words, interferes with reactivation of neocortical representations that are part of the memory trace. Competition is created as the memory and distracting tasks compete for the same representational system. The data presented in Chapter 2 are consistent with this account of DA effects.

An alternative account of these results is that the large memory costs, from similar material in a distracting task, is due to competition for general attentional resources, such as those mediated by the frontal lobes. As mentioned in Chapter 2, these resources may be needed to coordinate the online processing of dual-tasks. In the case of the word-based distracting tasks, retrieval may be disrupted to a relatively greater extent because the similarity in materials makes it more difficult to coordinate the two tasks, and overextends a limited pool of general processing resources.

For example, Craik (1983; in press) has suggested that the ability to retrieve an item from memory can be likened to the ease of pulling out a target from among different backgrounds or distracters, in perceptual experiments. That is, one’s ability to pick out the target is easier when the background offers a high contrast as opposed to a low contrast. The ability to resolve target items is reduced when it is among other materials that are highly similar. In order to pull out a target item successfully in this case, one must expend a greater amount of resolving power.

In terms of memory performance, resolving power can be interpreted to mean general processing resources. In the case where attention is divided between a memory and distracting task, it
may be that tasks which use similar materials make greater attentional demands than tasks which use dissimilar materials. As attentional resources are limited, this results in a break-down of the retrieval process, accounting for the large interference effect observed from word-based distracting tasks on retrieval.

Another resource-based account of the large material-specific effect of DA at retrieval, is that competition is created for an input-output channel. Processing of incoming words for the distracting task may require a verbal working memory system, while at the same time, words for the recall task may need the same resources, before output. It is in line with Baddeley's (1986;1992) hypothesis that the ability to coordinate concurrent tasks relies on the central executive (CE), whose operation requires resource mediated by PFC, in his working memory model. Coordination of concurrent tasks that require the same slave sub-system, in his model, is more difficult than when tasks require the verbal and visuo-spatial sub-system respectively, because in the former case they are relying on a common pool of resources. Such an account suggests that words to be recalled are successfully reactivated, but then disrupted during output. The component process model, on the other hand, suggests interference occurs during reactivation of the memory traces, prior to output, and that interference is not based on competition for general resources needed for PFC (and CE) function.

One way of testing the resource versus component-process account of interference effects, is to consider the performance of older individuals under DA conditions. It is well known that aging is accompanied by a decline in long-term episodic memory. A theoretical account of age-related decline in memory is that general processing resources that are critical for numerous cognitive operations decline with age (Craik, 1983; Craik & Byrd, 1982; Rabinowitz, Craik, & Ackerman, 1982). These resources have also been conceptualized in terms of reduced working memory capacity (Salthouse, 1996), needed
to hold and manipulate information or make computations (Craik & Jennings, 1992; Hasher & Zacks, 1988).

Regardless of how these resources are conceptualized, cognitive aging theorists suggest that changes in brain function, particularly in the frontal lobes, underlie the reduction in resources (e.g. Baddeley & Wilson, 1988; Fuster, 1997; Knight & Grabowecky, & Scabini 1995; Luria, 1966; Shallice & Burgess, 1991). Evidence of differences in frontal lobe function between young and old have been shown behaviourally (Moscovitch & Winocur, 1999), and in several neuro-imaging studies. When performing a retrieval task, older adults show a reduction in right PFC (and corresponding increase in left PFC) compared to young adults, who exhibit frontal lobe activation primarily on the right side (Cabeza et al., 1997; Madden et al., 1999). There is also some evidence of age-related reductions in cerebral volume (Coffey et al., 1992), in regional cerebral blood flow (Gur et al., 1987), and metabolic rates for oxygen and glucose (Leenders et al., 1990; Pantano et al., 1984), particularly in the frontal lobe, though there is much individual variation.

Overview of Chapter 3

A consideration of DA effects in older adults allows one to determine whether competition for general processing resources, and the frontal lobes, play a role in mediating large interference effects at retrieval. As described in the component-process model, the frontal lobes are central systems that require general resources for their operations. When the frontal lobes deteriorate, they draw on an even greater amount of resources in order to carry out operations effectively. If interference from DA occurs due to a reduction in available processing resources, then performance of those with poor frontal function should show amplified interference since they require more resources to maintain performance even under full attention.
Previous work comparing the performance of younger and older adults under DA conditions at retrieval found that using non-verbal distracting tasks had little effect on memory (Anderson et al., 1998; Macht & Buschke, 1983; Nyberg, Nilsson, Olofsson, & Bäckman, 1997; Park, Smith, Dudley, & Lafronza, 1989; Whiting & Smith, 1997). Performance on the distracting task, however, was disrupted more in older than younger adults (Anderson et al., 1998; Craik & McDowd, 1987; Whiting & Smith, 1997). This led Anderson et al. to conclude that older adults have a reduction in resources available to engage in demanding operations, as indexed by higher distracting task costs, but relatively preserved retrieval operations. That is, in agreement with Salthouse, Rogan, & Prill (1984), older adults can effectively maintain retrieval under DA conditions, however, they do so at a relatively greater cost to attentional resources.

In terms of the component process model, memory was not disrupted in these studies as retrieval on tests mediated primarily by the MTL/H proceeds obligatorily. Performance on the distracting task was affected, under DA conditions, as this measure reflects the resource-demanding aspect of retrieval: establishing and maintaining retrieval mode, and monitoring output, all of which are mediated by the PFC.

In this study, I tested the prediction based on the component-process model that the large interference effect from word-based distracting tasks is due to competition for common representations, in the posterior neocortex, rather than for general resources, required by the frontal lobes.

In Experiment 4 of this thesis, I assessed memory in young and old adults under full and divided attention conditions. Because older adults have deficits in episodic memory, I sought to equate the baseline level of recall between young and old by allowing the older adults to listen to the study list twice instead of just once as in the young adults. In Experiment 5 I considered the performance of
another group of older adults in which the study list was heard only once. In Experiment 6, I further evaluate the component-process model, in terms of possible brain regions mediating the effects. Here I examine performance under DA conditions, in a population of older adults, classified by level of dysfunction in temporal and frontal lobe function.

Experiment 4

Introduction

The question of interest for the present experiment is whether the large material-specific interference effects documented in young adults (Fernandes & Moscovitch, 2000, submitted) are due to a reduction in general processing resources from the DA condition, or to competition for representational systems. To address this question I considered whether older adults, with presumed reduced general processing resources would show interference effects, from DA at retrieval, that were larger in magnitude than those observed in young adults.

In the present experiment I sought to determine the effects of aging on two different types of distracting tasks. I compared directly a digit task, which has been shown to interfere little with memory for a list of words (Anderson et al., 1998; Craik & McDowd, 1987; Park et al., 1989; Whiting & Smith, 1997) in young and old adults, and a word-based distracting task whose interfering effects are substantial in young adults (see Experiment 1 of this thesis).

As predicted by the component-process model, I do not expect the size of the interference effect to differ between young and old, when either the word-animacy or odd-digit distracting task is concurrently performed. Insofar as interference occurs on the memory task, it is due to competition for a representational system, which is relatively well preserved in the older adults, and not due to competition for general processing resources in the PFC, which are compromised in this group. A
general-resource account of the effect predicts that interference will be greater in older adults, because their general processing resources are reduced.

It is possible, however, that older adults may remember fewer items overall, since episodic memory declines with age (Craik & Jennings, 1992; Salthouse, 1991). To equate baseline memory performance with young, I presented the study word list twice to older adults instead of just once as I did to the young adults.

In addition to the effects of DA on memory performance, I wanted to examine how costs to the distracting task were affected by DA conditions with retrieval. To do so, I compared the effect of the target memory task on accuracy and reaction time on the distracting tasks. As predicted by both the component-process and reduced-resource model, older adults are expected to show larger costs on the distracting task than younger adults; such costs are thought to be incurred in maintaining retrieval mode (Anderson et al., 1998; Craik et al., 1996; Fernandes & Moscovitch, 2000), a resource-demanding function ascribed to PFC, and which is compromised in older adults.
Method

Participants

Participants were 24 university undergraduate students at the University of Toronto, who received course credit or monetary compensation, respectively, for participating in the study. 24 seniors were chosen from a pool of volunteers used for studies at Erindale College, recruited by ads in the local newspaper, and received token monetary compensation for participating. The mean age was 19.54 (SD = 1.14) for the young and 71.69 (SD = 2.82) for the older adults. The mean number of years of education for the undergraduates was 14.2 (SD = 1.1) and for the older adults was 14.5 (SD = 1.9). All participants were native English speakers, and had relatively normal or corrected to normal vision and hearing. The Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975) was administered to each older adult. The mean score on the MMSE was 27.7 (SD = 0.88). Participants with a score of less than or equal to 26/30 were replaced.

Overview of experiment

The procedure for young and older adults was similar to that used in the previous experiments, except that word-animacy and odd-digit identification were the distracting tasks.

For the older adults, the study words were played at a louder volume. The volume was adjusted for each participant during the practice phase, to a level at which the older adult could hear the words clearly without straining their hearing. Additionally, in order to equate baseline recall between the age groups, the study word list was played twice during the experimental session for the older adults.

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4 Data from three young adults were excluded from Experiment 4 because the number of words they recalled in the full attention condition was 4 words or less. Due to experimenter error, the data for one participant were invalid. Additional participants were tested in their place.

5 Data from three older adults were excluded from Experiment 4: One participant misunderstood instructions, and another had serious hearing problem; due to experimenter error data from another participant were invalid. Additional participants were tested in their place.
Materials and Method.

Target recall task.

The materials used for the memory task were the same as in experiments from the previous chapter.

Distracting tasks

Animacy decisions. The materials used for this distracting task were the same as in the word-animacy task from Experiment 1.

Odd-digit decisions. Four 50-digit lists, and one 20-digit list were created by choosing a string of numbers, pseudo-randomly, from a table of random numbers. Each list was created such that half of the numbers were odd and half were even. Stimuli for the digit-monitoring task were two-digit numbers chosen from a table of random numbers (Kirk, 1995). In the ‘odd-digit’ task, two-digit numbers were displayed on the computer screen at a rate of one number every 2 seconds. Participants were told to press a key, using the index finger of the dominant writing hand, if the presented number was odd.

Arithmetic task. The materials and procedure were the same as in experiments from the previous chapter.

Comparing difficulty of the distracting tasks.

It is possible that the word and digit-based distracting tasks differ with respect to level of difficulty and resource requirements; this could contribute to any differences in their effects on retrieval. I assessed the relative resource demands of each task, in our group of younger adults. I looked at the effect each task had on a concurrently performed auditory continuous reaction time (CRT) task.

This was examined in the group of younger adults only. In a pilot experiment, older adults had difficulty in discriminating tones on the auditory CRT task, even under full attention, a finding
consistent with hearing loss in the aged.

Results

Target memory task analysis

In both young and older adults, the animacy distracting task interfered substantially with free recall performance. In both groups, the odd-digit task had a much smaller effect on memory. The means for each condition are presented in Table 7 for young adults and Table 8 for older adults. The following results were significant at $p < .001$ unless otherwise noted.

There were no significant main effects or interactions with the order factor (Order of experimental) on free recall performance in the young adults. For the older adults, there was no effect of Order of experimental condition, but the Order X Condition interaction was significant ($F = 3.16$, $MSE = 2.61$, $p < .01$). For one of the two orders of experimental conditions, in which the animacy DA condition was the last experimental condition to be performed, the number of words recalled was disproportionately low. This could account for the significant interaction. Moreover, for almost all of the participants (21/24), the mean number of words recalled was higher in odd-digit DA conditions than in the animacy DA condition, regardless of order of experimental conditions. Separate analyses were carried out using the number of words recalled and percentage decline in memory as dependent variables.

Number of words recalled

These analyses were carried out using Aging (young and old) as a between subject factor and Experimental condition (full attention, DA animacy, DA odd-digit) as a within subject factor. There was no effect of Aging on number of words recalled in the experimental conditions. Importantly, there was no effect of Aging on the number of words recalled in the full attention (baseline) condition, $t(46)$
= 1.70, p > .05, indicating that I was successful in equating baseline levels of recall in young and old. There was a main effect of Experimental condition $F (2, 92) = 30.42$, \textit{MSE} = 3.01. The Aging $X$ Experimental condition interaction was non-significant $F (2, 92) = 1.08$, \textit{p} > .05. The mean number of words recalled in the animacy, but not the odd-digit DA condition, differed significantly from the mean in the full attention condition, $F (1, 46) = 40.39$, \textit{MSE} = 7.68. The difference in number of words recalled between the animacy and odd-digit DA condition was significant, $F (1, 46) = 53.33$, \textit{MSE} = 4.39.

\textbf{Percentage decline in memory under DA conditions.}

For the following analyses I considered the mean percentage decline (ratio of performance in Full and DA conditions) for each participant as the dependent variable, rather than the percentage decline of the mean absolute number of words recalled across these conditions. Analyses were carried out using Aging (young and old) as a between subject factor and DA Condition (DA animacy, DA odd-digit) as a within subject factor. There was no effect of Aging on percentage decline in memory in each of the DA conditions. There was a main effect of DA Condition $F (1, 46) = 57.79$, \textit{MSE} = 0.04, with the DA animacy condition producing much larger declines in memory than the DA odd-digit condition. The Aging $X$ DA Condition interaction was significant $F (1, 46) = 6.63$, \textit{MSE} = .04, \textit{p} < .05. Simple effect analysis shows that the percentage decline in memory did not differ for young and old adults in the animacy DA condition $t (36) = -0.29$, though it approached significance in the odd-digit DA condition $t (36) = 1.76$, \textit{p} = .09. Surprisingly, the older adults performed better in the odd-digit DA condition than in the full attention condition, accounting for the interaction.
Table 7

Experiment 4 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Change From Single to Dual-task Condition For Each Measure for young adults (N=24)

<table>
<thead>
<tr>
<th>Measure and condition</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target memory task</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words recalled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Attention</td>
<td>8.42</td>
<td>2.32</td>
</tr>
<tr>
<td>DA animacy</td>
<td>4.00</td>
<td>2.36</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>7.71</td>
<td>2.40</td>
</tr>
<tr>
<td>Percentage Decline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>27.22</td>
<td>24.85</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>6.52</td>
<td>25.24</td>
</tr>
<tr>
<td><strong>Distracting task</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline animacy</td>
<td>.91</td>
<td>.07</td>
</tr>
<tr>
<td>DA animacy</td>
<td>.72</td>
<td>.14</td>
</tr>
<tr>
<td>Baseline digit-id</td>
<td>.92</td>
<td>.06</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>.85</td>
<td>.10</td>
</tr>
<tr>
<td>Filler</td>
<td>.87</td>
<td>.13</td>
</tr>
<tr>
<td>Percentage decline in accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>20.10</td>
<td>16.56</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>7.50</td>
<td>13.85</td>
</tr>
<tr>
<td>Reaction time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline animacy</td>
<td>790.86</td>
<td>100.99</td>
</tr>
<tr>
<td>DA animacy</td>
<td>1004.67</td>
<td>148.53</td>
</tr>
<tr>
<td>Baseline digit-id</td>
<td>638.08</td>
<td>88.57</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>792.17</td>
<td>126.82</td>
</tr>
<tr>
<td>Percentage increase in reaction time</td>
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<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>20.49</td>
<td>10.15</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>18.34</td>
<td>11.60</td>
</tr>
</tbody>
</table>

Note: DA = divided attention
**Table 8**

Experiment 4 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Change From Single to Dual-task Condition For Each Measure for older adults (N=24)

<table>
<thead>
<tr>
<th>Measure and condition</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target memory task</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words recalled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Attention</td>
<td>7.17</td>
<td>2.75</td>
</tr>
<tr>
<td>DA animacy</td>
<td>4.50</td>
<td>2.54</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>7.21</td>
<td>2.43</td>
</tr>
<tr>
<td>Percentage Decline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>30.16</td>
<td>43.84</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>-11.72</td>
<td>44.05</td>
</tr>
<tr>
<td><strong>Distracting task</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline animacy</td>
<td>.90</td>
<td>.08</td>
</tr>
<tr>
<td>DA animacy</td>
<td>.66</td>
<td>.19</td>
</tr>
<tr>
<td>Baseline digit-id</td>
<td>.92</td>
<td>.06</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>.78</td>
<td>.17</td>
</tr>
<tr>
<td>Filler</td>
<td>.86</td>
<td>.13</td>
</tr>
<tr>
<td>Percentage decline in accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>26.95</td>
<td>21.29</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>15.13</td>
<td>19.52</td>
</tr>
<tr>
<td>Reaction time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline animacy</td>
<td>857.79</td>
<td>140.82</td>
</tr>
<tr>
<td>DA animacy</td>
<td>1092.25</td>
<td>129.84</td>
</tr>
<tr>
<td>Baseline digit-id</td>
<td>655.13</td>
<td>110.19</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>834.25</td>
<td>139.78</td>
</tr>
<tr>
<td>Percentage increase in reaction time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>20.85</td>
<td>13.84</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>20.11</td>
<td>14.25</td>
</tr>
</tbody>
</table>

Note: DA = divided attention
Following each DA condition, the participants were given the chance to recall words from the target task under full attention. Few participants recalled any additional words. Young adults recalled only 0.38 (SD = 0.65) words following the animacy DA condition, and 0.25 (SD = 0.44) words following the odd-digit DA condition. Older adults recalled only 0.92 (SD = 1.25) and 0.42 (SD = 0.78) words following the animacy and odd-digit DA conditions respectively.

Distracting tasks analysis

Accuracy rates (calculated as #hits/15 - # false alarms/15) on the animacy and odd-digit distracting task, in the DA conditions, were much worse than single-task performance. The percentage decline in accuracy rate was larger on the animacy than odd-digit task for both groups. The means for each condition and age group are presented in Table 7 and 8. There were no significant main effects or interactions with the order factors (Order of experimental conditions and Order of single-task measure for each distracting task) on accuracy rate, or percentage decline in accuracy, for either age group. Separate analyses were conducted using the accuracy rate (hits - false alarms) and percentage decline in accuracy (from single-task) as dependent variables.

Accuracy rate

These analyses were conducted using Aging (young and old) as a between subject factor and Condition (single-task for animacy and odd-digit, and DA for animacy and odd-digit) as a within subject factor. There was no effect of Aging on accuracy rate in each condition $F (1,46) = 2.80, p > .05$. There was a main effect of Condition $F (3, 138) = 45.66, \text{MSE} = .011$, but the Aging X Condition interaction was non-significant $F (3,138) = 1.29, p > .05$. Accuracy rate on both distracting tasks under DA conditions differed significantly from their respective single-task baseline performance ($F (1, 46) =$
These analyses were carried out using Aging (young and old) as a between subject factor and DA Condition (DA animacy, DA odd-digit) as a within subject factor. There was no effect of Aging on percentage decline in accuracy in each of the DA conditions, \( F(1,46) = 2.70, p > .05 \). There was a main effect of DA Condition \( F(1,46) = 19.35, \text{MSE} = 0.02 \), with the DA animacy condition producing much larger declines in accuracy than the DA odd-digit condition. The Aging \( \times \) DA Condition interaction was not significant \( F(1,46) = 0.02, p > .05 \).

**Reaction Time.**

An analysis was conducted using Aging (young and old) as a between subject factor and Condition (single-task for animacy and odd-digit, and DA for animacy and odd-digit) as a within subject factor. There was no effect of Aging on RT in each condition \( F(1,46) = 3.78, p > .05 \). There was a main effect of Condition \( F(3,138) = 150.38, \text{MSE} = 8685.27 \), but the Aging \( \times \) Condition interaction was non-significant \( F(3,138) = 1.29, p > .05 \). Another analysis was conducted using Aging (young and old) as a between subject factor and DA Condition (DA animacy, DA odd-digit) as a within subject factor. There was no effect of Aging on percentage increase in RT under each the DA condition, \( F(1,46) = 0.14, p > .05 \). There was no main effect of DA Condition \( F(1,46) = 0.39 \), and the Aging \( \times \) DA Condition interaction was not significant \( F(1,46) = 0.09, p > .05 \).

The reaction times to respond on each distracting task, in the single-task baseline and dual-task conditions, are noted in Table 7 and 8. The baseline RT was significantly longer for the animacy than odd-digit distracting task \( t(22) = 9.53 \) for young adults and \( t(14) = 8.20 \) for the older adults) for both age groups. The percentage increase in RT, from single to dual-task conditions was not different for
the animacy and odd-digit tasks, in either age group.

Auditory CRT in young adults

The data from only 22 of the 24 young participants were available for this analysis. Due to experimenter error, data for 2 participants were lost.

Distracting task

The accuracy rate for both of the distracting tasks was similarly affected when the auditory CRT task was performed concurrently. There was no effect of task order on accuracy rates. The mean accuracy rate on the animacy and odd-digit tasks, performed concurrently with the CRT tone task, was .69 (S.D. = .14) and .71 (S.D. = .14) respectively. The difference between these two accuracy rates was not significant.

CRT tone task

The difference in the number of tones correctly identified in each DA condition was significant. The mean number of correct responses for each condition is presented in Table 9. A within participant ANOVA showed a main effect of condition $F(2, 42) = 99.62$, $MSE = 40.94$. The main effect of Order and the Order X Condition interaction was non-significant. Planned comparisons showed the number of tones correctly identified in the animacy and odd-digit DA conditions differed significantly from the full attention baseline condition ($F(1, 21) = 125$, $MSE = 116.49$ and $F(1, 21) = 141.19$, $MSE = 66.06$, respectively). The number of tones identified in the animacy dual-task condition was significantly lower than in the odd-digit dual-task condition ($t(20) = -3.03$, $p < .01$).
Table 9

Experiment 4 - Number of Correct Responses, Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition for young adults (N=24)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Correct response</th>
<th>Reaction time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>97.82</td>
<td>793.90</td>
</tr>
<tr>
<td>DA man-made</td>
<td>72.09</td>
<td>956.26</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>77.23</td>
<td>908.35</td>
</tr>
</tbody>
</table>

Note. DA = divided attention

The mean RT to identify tones is shown for correct responses only (see Table 9). An outlier analysis eliminated RTs greater or lesser than two standard deviations from the mean for each participant in each condition. A within participant ANOVA indicated a main effect of Condition $F (2, 42) = 16.51, \text{MSE} = 9271.51$. There were no significant main effects or interactions with Order.

The mean RT in both of the dual-task conditions differed significantly from the mean in the baseline condition ($F (1, 21) = 31.83, \text{MSE} = 18218.64$ and $F (1, 21) = 12.10, \text{MSE} = 23821.35$, respectively). The RT on the CRT task, performed under dual-task conditions with the animacy and odd-digit task, did not differ ($F (1,21) = 3.72, p > .05$). These results indicate that the two distracting tasks make similar resource demands or have similar levels of difficulty. I assume that the same level of difficulty would apply to the older adults.

Discussion

The major finding from this experiment is that young and old adults were similarly affected by the DA conditions. Older adults, with a presumed reduction in available processing resources, did not
show interference effects that were larger in magnitude to those observed in young adults. The word-based distracting task interfered substantially with retrieval, but the size of the effect was not amplified in the old compared to young adult group. As in previous studies, DA at retrieval using a non-verbal distracting task did not produce as large an effect in either group. These findings support the component-process model account of DA effects. As suggested by Fernandes and Moscovitch (2000), retrieval on memory tests mediated primarily by the MTL/H proceed obligatorily. It is only when there is competition for representational systems, as in the DA condition using a word-based distracting task, that retrieval is disrupted. Because this system is believed to be relatively intact in older adults, and according to the model, requires few general processing resources for its operation, the pattern of interference effects is similar in older adults to that of younger adults.

If DA produced interference by reducing the availability of general resources, then older adults should have been affected even more than young when the word-based distracting task was performed during retrieval. Moreover, they should also have had difficulty when the distracting task was non-verbal. My results suggest that the ability to retrieve items from memory while attending to competing irrelevant material is not affected by aging. The reduction in processing resources that characterizes older adults does not affect retrieval under dual-task conditions.

It should be noted that the difference in interference effects from the animacy compared to odd-digit task is not due to differences in resource requirements or task difficulty. The auditory CRT task in the young adults, performed concurrently with each of the distracting tasks, allowed a direct analysis of distracting task difficulty and resource requirements. Results showed that the two distracting tasks had similar effects on RT in the auditory CRT task, and that the accuracy rates on the distracting task were not significantly different under DA conditions with the tone task, at least in young adults. This
suggests that the two-distracting tasks were equally difficult and resource demanding.

In line with previous work (Anderson et al., 1998; Macht & Buschke, 1983; Nyberg et al., 1997; Park et al., 1989; Whiting & Smith, 1997), DA using the non-verbal distracting task (odd-digit task) did not affect memory performance substantially. Thus, the present results, as well as that of others argue against the hypothesis that reduced processing resources or attentional capacity in old age accounts for age differences in episodic retrieval. If it did, older adults should have had a harder time compensating for the reduction in available attention in either of our DA conditions.

It is possible, however, that in my effort to equate baseline levels of recall in young and old, by allowing older adults to listen to the study list twice instead of once, I prevented the older adults from experiencing interference which would otherwise have affected their memory performance. This may have given them more time to rehearse the target word list, and possibly to create more robust memory traces that are less susceptible to disruption. This possibility is examined in the next experiment.

Unlike previous work (Anderson et al., 1998; Craik & McDowd, 1987; Whiting & Smith, 1997) that examined performance decrements on the distracting task, the decline in performance from single-to dual-task conditions for the odd-digit and animacy tasks was not significantly elevated in older compared to younger adults, though there was a trend for higher costs in older adults. Failure to find larger distracting task costs in older adults was unexpected. Even when accuracy rate was measured during only the first half of the DA condition, when most of the words are being recalled, there was no age difference in distracting task costs.

If such costs reflect the resource-demanding aspect of retrieval (i.e. maintaining retrieval mode, monitoring output), and are mediated by the PFC, then older adults should have been affected more than our results indicate. Perhaps the difference in procedures during encoding, between young and old,
allowed the older adults to expend fewer resources to maintain retrieval mode, and monitor output; this would leave more resources available to devote to the distracting task. I test this possibility in the next experiment.

RT to make a response to distracting task items was longer in older adults, though not significantly. Also, the percentage change in RT from single to dual-task conditions did not differ with age. The longer RTs for the older adults likely occur due to differences in speed of processing (Salthouse, 1985; 1996). However, results indicate that this difference in speed does not lead to differences in retrieval from episodic memory, once initial learning is equated. The next experiment was conducted to examine the performance of older adults under DA, when the study opportunity was the same as that for young adults.
Experiment 5

Introduction

This experiment was conducted to determine whether age-related differences in effects of DA at retrieval would emerge when initial learning levels between older and younger adults were not equated. It is possible that allowing older adults to listen to the study list twice produced a more robust memory trace that masked greater susceptibility with aging to disruption from DA. In this experiment I tested another group of older adults, and allowed them to study the word list only once, as the young adults did in Experiment 4. I predicted that the pattern and magnitude of interference would remain the same as that of the older (and younger) adults in Experiment 4, because interference from DA at retrieval occurs due to competition for common representations, and not due to competition for general processing resources, which are believed to be compromised in older adults. By limiting the number of times the study list is heard to one, the overall number of words recalled by older adults in this experiment should be lower than that of the older adults in Experiment 1. This prediction is in line with the finding that aging is associated with a decline in episodic memory (Craik & Jennings, 1992; Salthouse 1991), that may stem from difficulties with encoding, and/or elaboration at encoding (Craik, 1982, 1983, 1986).

This experiment also allowed me to consider whether the reason I did not find the expected age differences in distracting task costs, was that I compensated for the older adults’ memory loss by providing them with additional learning. Because these costs are believed to reflect the general processing demands of retrieval (Anderson et al., 1998; Craik et al., 1996; Fernandes & Moscovitch, 2000), older adults, who are presumed to have fewer processing resources available to them, should have been more affected than young adults by the DA condition. In this experiment I expected that
distracting task costs would be larger than those observed in older adults in Experiment 4. That is, in addition to slower responses to distracting task items, accuracy rate should be affected to a greater extent than was observed in the group of older adults in Experiment 4.

Method

Participants

Participants were 166 older adults from the Erindale Seniors subject pool. Each received monetary compensation for participating. The mean age of participants was 69.40 (SD = 3.09). All participants were native English speakers, and had normal or corrected to normal vision and hearing, relative to their age-matched peers. The Mini-Mental State Exam (MMSE) was administered to each participant, with those obtaining a score of less than or equal to 26/30 being replaced. The mean score on the MMSE was 27.8 (SD = 0.6)

Materials and Method

Materials and procedures were identical to Experiment 4. The only difference was that the study word lists for the experimental session were played only once.

Results

Target memory task.

As in Experiment 1, the animacy distracting task produced a large interference effect on memory, whereas the odd-digit distracting task had no effect on free recall performance. The means for each condition are presented in Table 10. The data were analyzed using Order of experimental condition as a between subject factor and Experimental condition (full attention, DA animacy and DA odd-digit) as a within subject factor. The following results were significant at \( p < .001 \) unless otherwise

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\(^{6}\) Data from one senior were excluded due to mechanical difficulties with the tape recorder. Data from two seniors were excluded because they scored below 26/30 on the MMSE. Additional participants were tested in their place.
Number of words recalled.

There was an effect of Experimental condition, $F(2, 20) = 9.84$, $MSE = 1.56$, on free recall performance. There was an effect of Order ($F(5,10) = 3.80$, $MSE = 3.31, p < .05$), with poorer recall in the last experimental condition, but the Order X Experimental condition interaction was non-significant ($F = 1.13, p > .05$). This indicates that recall was generally poorer in the last experimental condition, regardless of whether it was the full attention or one of the DA conditions. The mean number of words recalled when the animacy task was performed concurrently with retrieval differed significantly from the mean in the full attention condition, $F(1, 15) = 18.78$, $MSE = 3.10$. The mean number of words recalled when the odd-digit task was the distracter did not differ from the mean in the full attention condition. The difference in number of words recalled in the animacy and odd-digit DA condition was significant, $F(1, 15) = 7.52$, $MSE = 4.40, p < .05$.

Percentage decline in memory under DA conditions.

For the following analyses I considered the mean percentage decline (ratio of performance in Full and DA conditions) for each participant as the dependent variable, rather than the percentage decline of the mean absolute number of words recalled across these conditions. The mean percentage decline in words recalled differed for the two DA conditions ($t(14) = 2.58, p < 0.05$). There was a larger decline in the animacy than odd-digit DA condition.
Table 10

Experiment 5 - Number of Words Recalled, Accuracy Rates and Reaction Times (in milliseconds) on Distracting Tasks, and Percentage Change From Single to Dual-task Condition For Each Measure for older adults (N=16)

<table>
<thead>
<tr>
<th>Measure and condition</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target memory task</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Words recalled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Attention</td>
<td>5.06</td>
<td>1.77</td>
</tr>
<tr>
<td>DA animacy</td>
<td>3.44</td>
<td>1.36</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>4.88</td>
<td>2.16</td>
</tr>
<tr>
<td>Percentage Decline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>28.61</td>
<td>23.72</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>-1.55</td>
<td>46.33</td>
</tr>
<tr>
<td>Distracting task</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline animacy</td>
<td>.93</td>
<td>.05</td>
</tr>
<tr>
<td>DA animacy</td>
<td>.74</td>
<td>.17</td>
</tr>
<tr>
<td>Baseline digit-id</td>
<td>.94</td>
<td>.06</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>.81</td>
<td>.18</td>
</tr>
<tr>
<td>Filler</td>
<td>.89</td>
<td>.11</td>
</tr>
<tr>
<td>Percentage decline in accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>20.17</td>
<td>19.90</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>13.24</td>
<td>20.94</td>
</tr>
<tr>
<td>Reaction time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline animacy</td>
<td>843.81</td>
<td>110.60</td>
</tr>
<tr>
<td>DA animacy</td>
<td>1031.63</td>
<td>161.99</td>
</tr>
<tr>
<td>Baseline digit-id</td>
<td>624.13</td>
<td>121.72</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>775.81</td>
<td>108.05</td>
</tr>
<tr>
<td>Percentage increase in reaction time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DA animacy</td>
<td>16.91</td>
<td>13.16</td>
</tr>
<tr>
<td>DA digit-id</td>
<td>19.22</td>
<td>11.72</td>
</tr>
</tbody>
</table>

Note: DA = divided attention
Immediately following free recall under each DA condition, participants were given the chance to recall any additional words from the target study list, under full attention. Few participants recalled any additional words following the animacy (M = 0.44 SD = 0.73) and odd-digit (M = 0.44 SD = 0.73) DA conditions.

Distracting task analysis

Accuracy rates (calculated as #hits/15 - # false alarms/15) on the animacy and odd-digit distracting task, in the DA conditions, were much worse than in the single-task condition. The percentage decline in accuracy rate was larger on the animacy than odd-digit task, though the difference was not significant. The means for each condition are presented in Table 10. There were no significant main effects or interactions with the order factors (Order of experimental conditions and Order of single-task measure for each distracting task) on accuracy rate, or percentage decline in accuracy. Separate analyses were conducted using the accuracy rate (hits - false alarms) and percentage decline in accuracy (from single-task) as dependent variables.

Accuracy rate

There was a main effect of Experimental condition, $F (3, 45) = 10.40$, $MSE = 0.014$. The mean accuracy rates for each task, in each condition, are presented in Table 10. Accuracy rate on both distracting tasks under DA conditions differed significantly from their respective single-task baseline performance ($F (1, 15) = 18.01$, $MSE = 0.02$ and $F (1, 15) = 6.43$, $MSE = 0.04$, $p < .05$, for the animacy and odd-digit task respectively).

Percentage decline in accuracy under DA conditions

The percentage decline in accuracy rate, for the animacy and odd-digit DA conditions, did not differ significantly from each other ($t (14) = 1.49$, $p > .05$).
**Reaction Time.**

The reaction time to respond on each distracting task, in the single-task and dual-task condition, is noted in Table 10. The single-task RT was significantly longer for the animacy than odd-digit distracting task \( t(14) = 8.20 \). The percentage increase in RT, from single- to dual-task condition, did not differ for the two distracting tasks.

**Comparison of memory performance with Experiment 4**

In order to compare the interference effects created under DA in this experiment to that found in the previous one, the data from Experiments 4 and 5 were re-analyzed using an ANOVA with Experiment as a between participant factor. A separate analysis was carried out for the number of words recalled, percentage decline in recall performance and percentage decline in accuracy on distracting tasks under DA conditions.

The main effect of Experiment on overall number of words recalled was not significant. However, planned Bonferroni comparisons (with alpha = .05) showed that older adults in Experiment 5 recalled fewer words in the full attention and DA odd-digit condition than the older and younger adults from Experiment 4. The number of words recalled in the DA animacy condition was significantly lower for participants in Experiment 5 than young, but not older adults from Experiment 4. The effect of experimental Condition was significant \( F(2, 122) = 34.25, \text{MSE} = 2.67 \), though the Condition X Experiment interaction was not significant \( F(4, 122) = 1.15 \).

The main effect of Experiment on percentage decline in recall under DA conditions was not significant, though the effect of experimental Condition was \( F(1, 61) = 51.23, \text{MSE} = 0.057 \). Importantly, the Condition X Experiment interaction was not significant \( F(2, 61) = 2.35 \), and there were no differences between the older adults from Experiment 4 and 5 on the percentage decline under
either DA condition. Thus the animacy distracting task, performed concurrently at retrieval, produced larger effects on retrieval than the odd-digit distracting task, but this pattern did not differ depending on age of participant, or number of study trials during encoding.

In the analysis of percentage decline in accuracy on distracting tasks, the main effect of Experiment was not significant, but the effect of experimental Condition was, \( F(1, 61) = 18.50 \), MSE = 0.018. Notably, the Condition X Experiment interaction was not significant \( F(2, 61) = 0.47 \). There were no differences in the percentage decline in accuracy, on either distracting task, in the older adults from Experiment 5 compared to those in Experiment 4 or compared to young adults from that experiment.

Discussion

This experiment was conducted to determine whether equating initial learning between older and younger adults eliminates age differences in effects of DA that would otherwise be observed. Instead of giving older adults additional study trials, they received a single trial as did young adults in Experiment 4. As a result, older adults in this experiment recalled fewer words than those in Experiment 4, but the pattern and magnitude of interference effects remained the same. Thus, despite allowing older adults to listen to the study word list only once during encoding, the interference effects from DA at retrieval were not amplified in older adults.

As in the first experiment, the word-based distracting task produced an approximate 30% decline in memory from the full attention condition, whereas the odd-digit distracting task had no effect on memory. These results run counter to a reduced resource account of interference effects from DA at retrieval. If the large material-specific effect of DA at retrieval occurred because this condition required
more resources to coordinate the concurrent tasks, which in turn hampered recovery of memories, then older adults should have shown an amplified interference effect.

In this experiment I also investigated whether the absence of age differences in distracting task costs in Experiment 4 occurred because initial learning was equated between the young and old. I had expected larger costs in older adults in Experiment 5. Despite worse memory, performance decrements on the distracting tasks under DA condition were not larger than those observed in the sample of older adults in Experiment 4. In fact, the present sample of older adults showed even smaller costs to distracting task performance under DA conditions with retrieval.

One might suggest that the reason for the lack of age differences in distracting task costs is that our older adults were more high-functioning than those used in other studies. There are several indications, however, that this is not the case. In Experiment 5, older adults showed the expected lower levels of episodic memory characteristic of the aging population. They recalled fewer words in all conditions. Furthermore, the level of education of older adults in our sample is not different from that in other studies (Anderson et al., 1998; Craik & McDowd, 1987; Macht & Buschke, 1983; Whiting & Smith, 1997). I believe that the reason I did not find greater distracting task costs in our older adults is that our distracting tasks are not sensitive enough to differentiate the age groups. The sensitivity of my chosen distracting tasks, to discriminate levels of available resources, is examined in the next experiment.
Experiment 6

Introduction

In Experiments 4 and 5 I used a population of older adults to test whether competition for general processing resources could account for DA effects produced during retrieval. The reason for testing older adults was that aging is presumed to be associated with deficits in memory stemming from a reduction in general processing resources that are critical for numerous cognitive operations (Craik, 1983; Craik & Byrd, 1982; Rabinowitz, Craik, & Ackerman, 1982). These resources have been conceptualized in many ways, though most theorists suggest that changes in frontal lobe function underlie the deficits (see Introduction to this chapter for details).

Another brain region shown to decline with age, that is also related to episodic memory, is the medial temporal lobes (Moscovitch, & Winocur, 1992). The MTL/H has long been considered to be crucial for episodic memory (see Shimamura & Squire, 1987 for a review). The component-process model, which describes the role of these different brain regions on different tests of memory, proposes that the MTL/H is a modular system, and thus does not contribute to the effects of DA at retrieval. The results of my previous work are consistent with this claim (Fernandes & Moscovitch, 2000; Fernandes & Moscovitch, submitted). In this experiment I use performance on neuropsychological tests, as an external measure of level of functioning of the frontal and MTL/H, in a group of older adults, to evaluate more directly the contribution of these regions to interference effects from DA at retrieval.

There is evidence that suggests that not all cognitive functions are similarly affected by aging and the rate of decline may differ depending on the given function. Individuals also may differ with respect to which functions are most affected (Albert, 1988; Welford, 1993). This variability may have prevented me from finding an effect of Aging on interference in the memory and distracting tasks.
Gisky, Polster and Routhieaux (1995) took advantage of this variability to differentiate among groups of older adults, depending on their level of functioning. Using neuropsychological testing, the level of frontal and temporal lobe function for each individual was assessed, relative to the group as a whole. They conducted a factor analysis on a selection of neuropsychological tests thought to depend on frontal and temporal lobe function. From this, they were able to calculate two $z$ scores for each participant, one that represented a composite of frontal lobe (FL) function, and one representing functioning of the medial temporal (MTL) lobes. They were thus able to classify their pool of older adults according to level of frontal and temporal function (see Gisky et al., 1995 for details).

In the present experiment, I considered the performance of older adults in Gisky et al.'s population, under the same DA conditions as the participants in Experiments 4 and 5. Given that my previous work (Fernandes & Moscovitch, 2000; submitted) suggested competition for MTL did not underlie interference effects under DA conditions at retrieval, I predict that the level of temporal lobe function should not alter the magnitude or pattern of interference effects from the odd-digit and animacy distracting tasks. Furthermore, the effects of DA are believed to be due to competition for representations in the posterior neocortex, thus whether a participant has a high or low level of temporal lobe function should not influence the interference effect. Using the same reasoning, the level of FL functioning should not change the magnitude or pattern of effects of DA on memory. Experiments 4 and 5 allowed me to infer that FL functioning does not contribute to the interference effect on memory. In the present experiment, I expect that all of the participants will show a similar pattern and magnitude of memory interference to the older adults in Experiment 4 and 5. Because the MTL is important for episodic memory, during both encoding and retrieval, however, those with lower levels of functioning should recall fewer words under full attention conditions than those with normal levels of functioning.
In Experiments 4 and 5, I had expected older adults to show larger interference effects on the distracting tasks, as this measure is believed to reflect the resource-demanding aspect of retrieval (Anderson et al., 1998; Craik et al., 1996; Fernandes & Moscovitch, 2000). Establishing and maintaining retrieval mode, and monitoring output, are all believed to be mediated by the PFC, which is presumably compromised in older adults. The lack of an amplified effect of DA on distracting task costs could be interpreted to mean that the sample of older adults in Experiments 4 and 5 did not have a reduction in general processing resources, and are not representative of older adults in the general population. Alternatively, it could mean that costs to our chosen distracting tasks do not reflect the resource-demands of retrieval. The present experiment allows me to distinguish between these alternative interpretations.

I compare the performance of older adults with higher versus lower levels of frontal lobe functioning, relative to the group as a whole. Because I will have an independent measure of frontal lobe functioning with which to classify older adults, I can consider whether low levels of function lead to higher distracting task costs; this is expected if costs reflect the resource-demanding aspect of retrieval, which are presumed to be mediated by the frontal lobes.

Because giving older adults additional study trials did not alter the magnitude or pattern of effects of DA, we allowed the group of older participants in this study to listen to the study list twice.

Participants

Seniors were selected from a larger pool of healthy, community-dwelling adults over the age of 65, who had undergone extensive neuropsychological testing within two years of experimental testing at the University of Arizona. Each participant in the pool had been assigned two scores, one representing
relative performance on a group of tests associated with FL function and the other representing relative performance on a group of tests believed to assess MTL function.

The tests comprising the FL factor were: number of categories achieved on the modified Wisconsin Card Sorting Test (Hart, Kwentus, Wade & Taylor, 1988), the total number of words generated on the FAS test (Spreen & Benton, 1977), Mental Arithmetic from the Wechsler Adult Intelligence Scale – Revised (WAIS-R; Wechsler, 1981), Mental Control from the Wechsler Memory Scale – revised (WMS-R; Wechsler, 1987), and Backward Digit Span from the WMS-R.

The tests comprising the MTL factor include: Logical Memory I, Verbal Paired Associate I, and Visual Paired Associate II (all from the WMS-R) and the Long-Delay Cued Recall measure from the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987).

These tests were grouped according to the results of two factor analyses: a) an exploratory principle factors analysis of data from 48 older adults (reported in Glisky et al., 1995), and b) a confirmatory factor analysis of data from a separate group of 100 older adults. In order to assess the differential contributions of the FL and MTL that were independent of age, variance attributable to age was removed from test scores prior to analyses. Composite scores were calculated for each individual in the pool; these represent average z-scores for those tests loading on each factor, relative to the 100-member normative group. Scores in the 100-member normative group were distributed such that 34 are above the mean for both the FL and MTL factor (denoted HH group in this experiment), 26 were below the mean on both factors (denoted LL group in this experiment), 18 were above the mean on the FL factor and below the mean on the MTL factor (denoted HL group in this experiment), and 22 were above the mean on the MTL factor and below the mean on the FL factor (denoted LH group in this experiment).
For the present experiment, 22 participants were selected from that pool of 100 older adults: 6 from the HH group, 5 from the LL group, 6 from the HL group, and 5 from the LH group. They received monetary compensation for their participation. Characteristics of each group are presented in Table 11. Separate one-way between-subjects ANOVAs indicated that there were no differences in age or education as a function of Group. There was an effect of Group on MMSE score (F (3, 18) = 5.71, p < .05); a Bonferroni post-hoc comparison showed that the LL group scored lower than the HH and LH group, however, scores greater than 26/30 are considered indicative of normal functioning. There was also an effect of Group on full scale IQ (F (3, 18) = 4.14, p < .05); a Bonferroni post-hoc test showed this effect was due to the LL group having a much lower IQ than the HH group.
Mean Characteristics (M + SD) of Groups Selected According to Frontal Lobe (FL) Function and Medial Temporal Lobe (MTL) Function, and Estimates of Published Normative Data on Neuropsychological Tests for Adults Aged 65 to 75 Years.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>HH group M + SD</th>
<th>LL group M + SD</th>
<th>LH group M + SD</th>
<th>HL group M + SD</th>
<th>Norm M + SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>72.5 + 3.9</td>
<td>73.2 + 3.4</td>
<td>71.6 + 3.5</td>
<td>74.8 + 6.3</td>
<td>---</td>
</tr>
<tr>
<td>Years of Education</td>
<td>15.6 + 2.7</td>
<td>13.9 + 2.1</td>
<td>14.5 + 3.2</td>
<td>16.6 + 6.3</td>
<td>---</td>
</tr>
<tr>
<td>MMSE</td>
<td>29.8 + 0.4</td>
<td>27.6 + 1.1</td>
<td>29.3 + 0.8</td>
<td>29.0 + 0.5</td>
<td>---</td>
</tr>
<tr>
<td>Full scale IQ</td>
<td>130.8 + 10.9</td>
<td>107.0 + 9.9</td>
<td>113.0 + 13.5</td>
<td>113.0 + 13.2</td>
<td>---</td>
</tr>
<tr>
<td>Wisconsin Card Sorting</td>
<td>6.0 + 0.0</td>
<td>4.2 + 1.3</td>
<td>2.8 + 1.5</td>
<td>5.8 + 0.5</td>
<td>5.2 + 1.4</td>
</tr>
<tr>
<td>Total words on FAS</td>
<td>50.7 + 4.2</td>
<td>32.6 + 6.1</td>
<td>33.5 + 6.5</td>
<td>50.6 + 3.7</td>
<td>39.2 + 11.9</td>
</tr>
<tr>
<td>WAIS –R Mental Arithmetic</td>
<td>15.5 + 2.5</td>
<td>10.8 + 2.9</td>
<td>11.83 + 3.4</td>
<td>15.8 + 2.9</td>
<td>12.0 + 4.0</td>
</tr>
<tr>
<td>WAIS –R Mental Control</td>
<td>5.83 + 0.4</td>
<td>4.8 + 1.3</td>
<td>5.3 + 0.8</td>
<td>5.6 + 0.9</td>
<td>5.0 + 1.5</td>
</tr>
<tr>
<td>Backward Digit Span</td>
<td>8.8 + 2.3</td>
<td>5.2 + 0.8</td>
<td>7.0 + 1.7</td>
<td>8.2 + 1.1</td>
<td>7.6 + 2.0</td>
</tr>
<tr>
<td>Logical Memory I</td>
<td>30.7 + 6.3</td>
<td>21.0 + 7.4</td>
<td>27.8 + 5.8</td>
<td>18.8 + 3.5</td>
<td>24.0 + 7.5</td>
</tr>
<tr>
<td>Verbal Paired-Associates I</td>
<td>21.7 + 1.5</td>
<td>18.4 + 4.2</td>
<td>21.0 + 1.5</td>
<td>17.2 + 3.9</td>
<td>16.5 + 4.0</td>
</tr>
<tr>
<td>Visual Paired-Associates II</td>
<td>5.8 + 0.4</td>
<td>4.6 + 0.8</td>
<td>6.0 + 0.0</td>
<td>5.4 + 0.9</td>
<td>4.0 + 2.5</td>
</tr>
<tr>
<td>CVLT Long Delay Cued Recall</td>
<td>13.7 + 0.8</td>
<td>10.0 + 1.9</td>
<td>13.83 + 1.5</td>
<td>9.8 + 3.6</td>
<td>10.3 + 3.7</td>
</tr>
<tr>
<td>Composite Score</td>
<td>FL 0.7 + 0.4</td>
<td>-0.6 + 0.4</td>
<td>-0.5 + 0.4</td>
<td>0.7 + 0.4</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>MTL 0.7 + 0.4</td>
<td>-0.5 + 0.3</td>
<td>0.5 + 0.3</td>
<td>-0.4 + 0.4</td>
<td>---</td>
</tr>
</tbody>
</table>

HH = high frontal/high temporal, LL = low frontal/low temporal, LH = low frontal high temporal, HL = high frontal, low temporal
Materials and Method

Materials and procedures were identical to those of Experiment 4. The only difference in procedure was that participants in this experiment were given only a short break in between the experimental session.

Results

Target memory task analysis. In all groups, the animacy distracting task interfered substantially with free recall performance. In all groups, the odd-digit task had a much smaller effect on memory. The means for each condition are presented in Table 12. The following results were significant at $p < .001$ unless otherwise noted.

The effect of the Order factor was non-significant as was the Condition X Order interaction. Separate analyses were conducted using the number of words recalled and percentage decline in memory as dependent variables.

Number of words recalled.

These analyses were carried out using Group as a between subject factor and Experimental condition (full attention, DA animacy, DA odd-digit) as a within subject factor. There was no effect of Group on number of words recalled across all experimental conditions. There was a main effect of Experimental condition $F(2, 36) = 16.44$, $MSE = 2.92$, but the Group X Experimental condition interaction was non-significant $F(6,36) = 0.46$.

Across all groups, the number of words recalled in the DA animacy condition was significantly less than that in the full attention condition, $F(1,18) = 27.63$, $MSE = 6.60$. The number of words recalled in the DA odd-digit condition, however, did not differ from that under full attention, $F(1,18) = 4.09$. The difference in number of words recalled
between the animacy and odd-digit DA condition was significant, $F(1, 18) = 12.91$, \(\text{MSE} = 6.93\).

A DUNCAN multiple-range test ($p = .05$) shows that the HH group recalled significantly more words under full attention than the LL group, and that the number of words recalled by the LH and HL groups under full attention did not differ from any other group. Because the number of participants in each group was small, data was collapsed across level of FL and MTL function. There was no significant difference in the number of words recalled under full attention, depending on frontal lobe classification (irrespective of MTL grouping), $F(1, 20) = 0.47$. There was a significant difference in words recalled under full attention, depending on level of temporal lobe functioning (irrespective of frontal lobe grouping), $F(1, 20) = 7.60$, \(\text{MSE} = 5.83\), $p < .05$. Adults with low MTL function recalled fewer words than those with high MTL function.

**Percentage decline in memory under DA conditions.**

Across groups, the percentage decline in memory, under DA conditions with the animacy task was significant, $t(20) = 5.91$. The decline under DA with the odd-digit task was non-significant, $t(20) = 1.01$, $p > 0.5$.

The remaining analyses were conducted using Group as a between subject factor and DA Condition (DA animacy, DA odd-digit) as a within subject factor. There was no effect of Group on the magnitude of decline in memory under DA conditions ($F(3, 18) = 1.11$). There was a main effect of DA Condition $F(1, 18) = 17.22$, \(\text{MSE} = 0.057\), with the DA animacy condition producing much larger declines in memory than the DA odd-digit condition. The Group X DA Condition interaction was not significant $F(3, 18) = 0.86$.

There were no differences in percentage decline in memory, depending on level of
frontal lobe function, $F_{(1,20)} = 0.35$, and $F_{(1,20)} = 2.09$, under DA conditions with the
animacy and odd-digit task respectively. There were also no differences, depending on
level of temporal lobe function, $F_{(1,20)} = 0.08$, and $F_{(1,20)} = 0.95$, under DA conditions
with the animacy and odd-digit task respectively.
Table 12

Experiment 6: Number of Words Recalled and Percentage Change From Single to Dual-task Condition For Each Measure in Each Group

<table>
<thead>
<tr>
<th>Measure and Group</th>
<th>Full Attention</th>
<th>DA animacy</th>
<th>DA digit-id</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Words Recalled</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HH group</td>
<td>8.5</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>LL group</td>
<td>4.8</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>LH group</td>
<td>8.0</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>HL group</td>
<td>6.0</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Percentage Decline in recall</td>
<td>39.3</td>
<td>29.8</td>
<td></td>
</tr>
<tr>
<td>HH group</td>
<td>27.1</td>
<td>43.3</td>
<td></td>
</tr>
<tr>
<td>LL group</td>
<td>40.0</td>
<td>26.6</td>
<td></td>
</tr>
<tr>
<td>LH group</td>
<td>44.8</td>
<td>26.2</td>
<td></td>
</tr>
</tbody>
</table>
Following each DA condition, the participants were given the chance to recall words from the target task under full attention. The number of additional words recalled following each DA condition, for each group, are presented in Table 13. A DUNCAN multiple-range test \( (p = .05) \) shows that the number of additional words recalled following the DA animacy condition did not differ across groups; the number of additional words recalled following the DA odd-digit condition was higher for the group with low frontal/high temporal function.

Because the number of participants in each group was small, data was collapsed across level of FL and MTL function. There was no significant difference in the number of additional words recalled following the DA animacy condition depending on frontal lobe classification (irrespective of MTL grouping), \( F (1,20) = 3.97 \) or depending on MTL classification (irrespective of frontal lobe grouping), \( F (1,20) = 0.06 \). Similarly, there was no significant difference in the number of additional words recalled following the DA odd-digit condition, depending on frontal lobe classification (irrespective of MTL grouping), \( F (1,20) = 0.53 \) or depending on MTL classification (irrespective of frontal lobe grouping), \( F (1,20) = 0.39 \).
Table 13

**Experiment 6: Additional Words Recalled Following each Divided Attention Condition for Each Group**

<table>
<thead>
<tr>
<th>Group</th>
<th>DA animacy M + SD</th>
<th>DA odd-digit M + SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HH group</td>
<td>0.66 ± 1.21</td>
<td>0.66 ± 0.82</td>
</tr>
<tr>
<td>LL group</td>
<td>2.20 ± 2.05</td>
<td>0.60 ± 0.89</td>
</tr>
<tr>
<td>LH group</td>
<td>3.17 ± 0.98</td>
<td>2.17 ± 0.98</td>
</tr>
<tr>
<td>HL group</td>
<td>1.80 ± 1.48</td>
<td>1.60 ± 1.34</td>
</tr>
</tbody>
</table>

**HH** = high frontal/high temporal, **LL** = low frontal/low temporal, **LH** = low frontal high temporal, **HL** = high frontal, low temporal
**Distracting tasks analysis**

Accuracy rates (calculated as #hits/15 - # false alarms/15) on the animacy and odd-digit distracting task, in the DA conditions, were much worse than under single-task performance. The percentage decline in accuracy rate did not differ in the DA animacy and DA odd-digit conditions, across groups. The means for each condition and age group are presented in Table 14. There were no significant main effects or interactions with the order factors (Order of experimental conditions and Order of single-task measure for each distracting task) on accuracy rate, or percentage decline in accuracy. Separate analyses were conducted using the accuracy rate (hits - false alarms) and percentage decline in accuracy (from single-task) as dependent variables.
Chapter 3: DA in young and old adults

Table 14

Experiment 6: Accuracy Rates on Distracting Tasks and Percentage Change From Single to Dual-task Condition for Each Measure
Table 14

Experiment 6: Accuracy Rates on Distracting Tasks and Percentage Change From Single to Dual-task Condition For Each Measure in Each Group

<table>
<thead>
<tr>
<th>Measure and Condition</th>
<th>Baseline animacy</th>
<th>DA animacy</th>
<th>Baseline digit-id</th>
<th>DA digit-id</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Accuracy rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HH group</td>
<td>.91</td>
<td>.04</td>
<td>.76</td>
<td>.16</td>
</tr>
<tr>
<td>LL group</td>
<td>.88</td>
<td>.06</td>
<td>.77</td>
<td>.11</td>
</tr>
<tr>
<td>LH group</td>
<td>.90</td>
<td>.06</td>
<td>.72</td>
<td>.11</td>
</tr>
<tr>
<td>HL group</td>
<td>.90</td>
<td>.06</td>
<td>.79</td>
<td>.13</td>
</tr>
<tr>
<td>Percentage decline in accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HH group</td>
<td>16.7</td>
<td>19.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL group</td>
<td>21.8</td>
<td>12.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LH group</td>
<td>19.4</td>
<td>14.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HL group</td>
<td>12.4</td>
<td>11.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: DA = divided attention
## Table 15
Experiment 6: Reaction Times (in milliseconds) on Distracting Tasks and Percentage Change From Single to Dual-task Condition For Each Measure in Each Group

<table>
<thead>
<tr>
<th>Measure and Condition</th>
<th>Baseline animacy</th>
<th>DA animacy</th>
<th>Baseline digit-id</th>
<th>DA digit-id</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Reaction Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HH group</td>
<td>863.5</td>
<td>84.6</td>
<td>1014.8</td>
<td>96.3</td>
</tr>
<tr>
<td>LL group</td>
<td>812.4</td>
<td>131.2</td>
<td>1006.2</td>
<td>122.1</td>
</tr>
<tr>
<td>LH group</td>
<td>813.3</td>
<td>112.6</td>
<td>984.2</td>
<td>83.2</td>
</tr>
<tr>
<td>HL group</td>
<td>814.0</td>
<td>67.0</td>
<td>1015.6</td>
<td>105.6</td>
</tr>
<tr>
<td>Percentage increase in reaction time</td>
<td>14.9</td>
<td>4.0</td>
<td>25.0</td>
<td>12.9</td>
</tr>
<tr>
<td>HH group</td>
<td>19.4</td>
<td>7.0</td>
<td>14.7</td>
<td>15.8</td>
</tr>
<tr>
<td>LL group</td>
<td>17.3</td>
<td>9.0</td>
<td>22.3</td>
<td>14.3</td>
</tr>
<tr>
<td>LH group</td>
<td>19.5</td>
<td>5.8</td>
<td>15.7</td>
<td>11.9</td>
</tr>
</tbody>
</table>

Note: DA = divided attention
Chapter 3: DA in young and old adults

Accuracy rate.

These analyses were conducted using Group as a between subject factor and Condition (single-task for animacy and odd-digit, and DA for animacy and odd-digit) as a within subject factor. There was no effect of Group on accuracy rate in each condition $F(3,18) = 0.83$. There was a main effect of Condition $F(3,54) = 13.50$, $\text{MSE} = 0.008$, but the Group X Condition interaction was non-significant $F(9,54) = 0.73$. Accuracy rate on both distracting tasks under DA conditions differed significantly from their respective single-task baseline performance ($F(1,18) = 21.33$, $\text{MSE} = 0.019$ and $F(1,18) = 26.61$, $\text{MSE} = 0.010$, for the animacy and odd-digit task respectively).

Percentage decline in accuracy under DA conditions.

Across groups, the percentage decline in accuracy rate from single to dual-task conditions, on the animacy and odd-digit task, was significant, $t(20) = 5.06$, and $t(20) = 4.77$, respectively. There were no differences in percentage decline in accuracy, depending on level of frontal lobe function, $F(1,20) = 0.04$, and $F(1,20) = 0.54$, for the animacy and odd-digit task respectively. There were also no differences, depending on level of temporal lobe function, $F(1,20) = 0.94$, and $F(1,20) = 1.77$, for the animacy and odd-digit task respectively.

The remaining analyses were conducted using Group as a between subject factor and DA Condition (DA animacy, DA odd-digit) as a within subject factor. There was no effect of Group on percentage decline in accuracy in the DA conditions, $F(3,18) = 0.35$. There was no main effect of DA Condition $F(1,18) = 0.52$, and the Group X DA Condition interaction was not significant $F(3,18) = 1.41$.

Separate ANOVAs were conducted using percentage decline for each DA
condition (individually) as the dependent variable and Group as the between subject factor. There was no effect of Group on the percentage decline in memory in the animacy or odd-digit DA conditions, $F(3,121) = 0.31$ and $F(3, 21) = 1.85$, respectively.

**Reaction Time.**

The reaction times to respond on each distracting task, in the single-task baseline and dual-task conditions, are noted in Table 15. There was no effect of order of single-task measures on RT, for either of the distracting tasks in any group.

The percentage increase in RT on the distracting tasks under DA conditions, did not differ depending on level of frontal lobe function, $F(1,20) = 0.21$, and $F(1,20) = 0.11$, for the animacy and odd-digit task respectively. The increase in RT did not differ depending on level of temporal lobe function either, $F(1,20) = 1.49$, and $F(1,20) = 2.27$, for the animacy and odd-digit task respectively.

The following analyses were conducted using Group as a between subject factor and DA Condition (DA animacy, DA odd-digit) as a within subject factor. There was no effect of Group on RTs in the DA conditions, $F(3,18) = 0.53$. The effect of DA condition was significant, $F(1,18) = 41.37$, $MSE = 6854.15$, but the Group X DA condition interaction was non-significant, $F(3,15) = 0.06$.

There was no effect of Group on the percentage increase in RT on the distracting tasks under DA conditions, $F(3,18) = 0.25$. The effect of DA condition on the increase in RT was non-significant, as was the interaction, $F(1,18) = 0.21$, and $F(3,18) = 1.02$. The increase in RT was similar for the animacy and odd-digit distracting task, $F(1,18) = 0.21$. 
Discussion

I used adults classified on the basis of neuropsychological test scores, as having good or poor FL and MTL function, to evaluate more directly the contribution of these regions to interference effects from DA at retrieval. According to the component-process model, the effects of DA arise from competition for representations, in the posterior neocortex. Thus, whether a participant has a high or low level of temporal lobe or frontal lobe function should not influence the extent of interference.

The finding that level of medial temporal lobe function does not contribute to interference under DA, is consistent with my previous work (Fernandes & Moscovitch, 2000), in which participants had to recall words and monitor simultaneously a list of visually-presented words in a running recognition test: In one DA condition, some words were repeated after at a lag of 3 or less, and in the other, at a lag of 7 or more, making it a test of short-term or long-term memory, respectively (see Tulving & Colotla, 1970). Both DA conditions were successful in producing a substantial decrement in recall of about 30% in comparison to the full attention condition. That there was no difference between the short and long lag conditions suggested that MTL, which is involved in LTM but not STM, was not the locus of the competition effect between the target and interfering memory tasks. Instead, the results suggested that the locus of the effect was at the level of neocortical representational systems involved in word perception and production.

Furthermore, the results are in line with those from Experiments 4 and 5, in which the reduction in available processing resources believed to characterize older adults, and attributed to deterioration in the frontal lobe, did not alter the pattern or magnitude of interference. If competition for resources accounts for the large effects of DA from word-
based distracting tasks, memory interference in participants with relatively poor FL function should have been amplified relative to those with better FL function, because the former have to compensate for an even greater reduction in available resources. Thus the results from this experiment argue against a resource account of DA effects at retrieval.

The only effects on memory were seen on the number of words recalled under full attention: those with relatively poor MTL function recalled significantly fewer words. This was expected because the MTL is important for episodic memory. Regardless of their lower baseline memory performance, the pattern and size of their interference effect was no different than that of the participants who had relatively higher levels of MTL function. Thus I have shown that whether the overall level of memory performance is affected naturally, in those with poor MTL function, or artificially by increasing the number of study trials, in the high-functioning older adults from Experiment 4 and 5, this does not influence the magnitude of memory interference from DA.

As in Experiments 4 and 5, DA using the animacy task produced very large levels of interference, ranging from 27-44 % drop in performance from full attention conditions, across groups. Smaller interference effects were observed when the odd-digit task was performed with recall (range -23% to 22%). These data support the claim that effects from DA at retrieval are modulated by the type of material in the distracting task. Thus, data in this chapter show that material-specificity of the distracting task is a major factor determining the magnitude of the effect on memory.

In Experiments 4 and 5, the lack of an amplified effect of DA on distracting task costs was unexpected. This could be interpreted to mean that the sample of older adults in these experiments did not have a reduction in general processing resources, and were not
representative of older adults in the general population. Alternatively, it could mean that costs to our chosen distracting tasks do not reflect the resource-demands of retrieval. This experiment allowed me to address these issues. Here I had an independent measure of frontal lobe functioning with which to classify older adults, and could consider whether low levels of functioning lead to higher distracting task costs; this is expected if costs reflect the resource-demanding aspect of retrieval, mediated by the frontal lobes. There was, however, no difference in costs to either distracting task, regardless of whether accuracy or RT was the measure used, between groups with relatively good or poor FL function.

Nevertheless, the finding of significant costs for each task, under dual-task conditions, suggests that retrieval is resource-demanding. What is more, the costs to the distracting task did not differ for the animacy and odd-digit task. Thus unlike the effects of different distracting tasks on memory, which are material-specific, effects on the distracting task must reflect some more general resource requirement.

General Discussion of Chapter 3 Experiments

The present chapter was aimed at determining whether large interference effects from DA at retrieval could be accounted for either by competition for general processing resources or for common representational structures. The work by Fernandes and Moscovitch (2000), as well as the work described in Chapter 2, suggests that performing a word-based task, concurrently with recall of words, interferes with reactivation of the neocortical representations that form part of a verbal memory trace. Competition is created as the memory and distracting tasks compete for the same representational system.
An alternative account of these results is that the large memory costs, from similar material in a distracting task, are due to a reduction in available resources for frontal lobe function. These resources may be needed to coordinate the online processing of dual-tasks. In the case of the word-based distracting tasks, retrieval may be disrupted to a relatively greater extent because the similarity in materials makes it more difficult to extract relevant items from memory, and/or coordinate their output, both of which overextend a limited pool of general processing resources. To compare these accounts, I considered the performance of older adults, whose cognitive resources are believed to be reduced, relative to young adults.

**Memory Costs**

In Experiments 4 and 5, young and old adults were similarly affected by the DA conditions. In both age groups, memory was much more affected by the animacy compared to odd-digit distracting task. Importantly, older adults did not show interference effects on memory that were larger in magnitude to those observed in young adults (see Figure 3).
Figure 3. Mean percentage decline in free recall performance from full to divided attention (DA) for each condition in Experiment (Expt.) 4 and 5, in young and older adults.
As in previous studies (Anderson et al., 1998; Macht & Buschke, 1983; Nyberg et al., 1997; Park et al., 1989; Whiting & Smith, 1997) DA at retrieval with a non-verbal distracting task did not produce very large effects on memory, and there was no interaction with age.

These results argue against a reduced resource explanation of interference effects on memory, and support the idea that retrieval is disrupted primarily when there is competition for common representational systems. Moreover, if competition for resources accounts for the large effects of DA from word-based distracting tasks, memory interference in participants with relatively poor FL function in Experiment 6 should have been amplified relative to those with relatively better FL function, but it was not (see Figure 4).
Figure 4. Mean percentage decline in free recall from single to divided attention for older adults with relatively high versus low frontal lobe function with each distracting task.
In Experiments 4 and 5, as well as in the LL group from Experiment 6, older adults performed better in the odd-digit DA conditions than under full attention during retrieval. I have no explanation for this finding, except that perhaps adding a simple distracting task raises arousal, which improves performance (see Kahneman, 1973).

An alternative interpretation to the component-process model, for the large material-specific DA effect, is that competition is created at the level of input-output channels in working memory. As suggested by Hasher and Zacks (1988), age-related differences in memory and other cognitive functions can be attributed to a decline in attentional inhibitory control over the contents of working memory. They suggest that older adults are more distracted by irrelevant information: reduced inhibitory control allows more "nongoal" information to enter working memory, thereby producing difficulty with memory. If DA at retrieval in my experiments disrupted memory by this means, however, older adults in Experiment 4 would have shown greater interference in the DA animacy (and DA odd-digit) condition relative to the young adults.

One puzzling difference in the findings across experiments, however, suggests that competition for output pathways may be another source of interference under dual-task conditions. In Experiments 4 and 5, both young and older participants recalled few, if any, additional words after the DA condition was terminated. That is, the effects of DA from the word-based distracting task persisted in both age groups. Such results are consistent with the notion that word-based distracting tasks interfere with memory by corrupting the memory trace (Fernandes & Moscovitch, 2000), prior to its being reported, and inconsistent with the possibility of competition for input-output channels in working memory. In Experiment 6, however, only the HH group showed the same persistent
effects of DA. The other groups of older adults recalled many more words after the DA condition was over, to the point of recovering from the material-specific interference effect from the animacy distracting task. These latter findings are more in line with an output interference account of DA effects. It may be that participants with poor MTL and/or FL function found the dual-task conditions so difficult that they did not try to recall words while doing the distracting task. That is, they may have switched back and forth between the two tasks, rather than try to carry out both simultaneously as did the normal functioning elderly (HH group), and the older adults from Experiments 4 and 5. This suggests that memory traces are not corrupted under DA conditions unless one is actively trying to carry out both tasks simultaneously, rather than in tandem. Despite this anomaly in additional words recalled following the DA conditions, there was still a larger interference effect from the animacy compared to odd-digit distracting task. Moreover, its magnitude was similar regardless of level of MTL or FL function. Thus competition for output channels is not the only source of interference.

Distracting Task Costs

According to the component-process model described in the Introduction, the resource-demanding aspect of retrieval lies in establishing and maintaining retrieval mode, as well as in monitoring output. These processes are thought to be mediated by the PFC. Insofar as the target task makes use of these processes, the resource demands should be reflected in costs to distracting task performance. Indeed such costs were noted in young adults. I expected that older adults would show larger costs under DA conditions since they are presumed to have fewer processing resources available to them than do young
adults, but this did not occur (see Figure 5). Moreover, distracting task costs did not differ in Experiment 6 depending on the level of frontal lobe function of participants (see Figure 6).
Figure 5. Mean percentage decline in accuracy rate from single to divided-attention (DA) for each condition in Experiment (Expt.) 4 and 5, in young and older adults.
Figure 6. Mean percentage decline in accuracy rate from single to divided-attention in older adults with relatively high versus low frontal lobe function for each distracting task.
If these costs are sensitive to availability of general processing resources, then those with lower levels of frontal function should have showed greater costs. As already mentioned, my chosen distracting tasks may not be sensitive enough to differentiate differences in available resources in young and old, and those with relatively poor frontal lobe function. In other studies where an age difference in distracting task costs was observed, the dependent measure was latency. Had I emphasized the importance of making responses quickly (I emphasized to participants the importance of accuracy rather than RT to respond), age differences in Experiments 4 and 5, and group differences in Experiment 6 might have emerged. One should keep in mind, however, that the costs to the distracting task were always significant, thereby illustrating that retrieval does make resource demands, though the present experiments do not allow us to ascribe these to the frontal lobe.

It could be that our distracting tasks were much easier than those used in other studies (Anderson et al., 1998; Craik & McDowd, 1987; Macht & Buschke, 1983; Whiting & Smith, 1997), where there were age differences in distracting task costs incurred by the DA condition. But if our tasks were easier, then the effect of the animacy task on memory should also have been smaller. Instead its effect on memory was quite substantial.

These results, together with others that showed no effect of aging on memory under DA at retrieval (Anderson et al., 1998; Craik & McDowd, 1987; Macht & Buschke, 1983; Nyberg et al., 1997; Park et al., 1989; Whiting & Smith, 1997), suggest that diminished availability of attentional resources is not the critical factor leading to disruptions in memory recovery under DA. Also, as suggested in previous work (Nyberg
et al., 1997), the finding of interference effects similar in magnitude between young and older adults provides no support for the notion that age-related deficits in episodic memory are related to reduced attentional capacity. That the pattern and magnitude of interference on memory, from either DA condition, did not differ in Experiment 6 depending on level of frontal lobe function provides further support for this claim.

**What can these results tell us about memory in older adults?**

Consistent with the component-process model, whether one has deterioration in FL or MTL function does not amplify susceptibility to disruption by DA; and while poor MTL function does lead to poorer memory, it does not lead to greater susceptibility to distraction. The data from Experiment 4 and 5 suggest that what declines with age is encoding and/or storage of new information (Morris, Gick, & Craik, 1988). The only differences in performance between young and older adults was that older adults recalled fewer words when given the single encoding phase in Experiment 5. The pattern of DA interference on memory, however, remained similar to young adults in Experiment 4. Because the different encoding conditions in Experiment 4 and 5 yielded different absolute levels of recall in the two samples of older adults, these data are more in line with the idea that aging is associated with poorer encoding and/or storage (Craik & Byrd, 1982; Rabinowitz et al., 1982).

In terms of the component-process model of retrieval, these data together with others which found no age-related increase in the effects of DA at retrieval from non-verbal distracting tasks, suggest that retrieval on associative tests of memory, proceeds obligatorily and is relatively immune to disruption. It is only when the memory task shares the same representational system as the distracting task that large effects on memory are
seen. According to the model, competition is in the brain regions representing the content of the memory trace, in the posterior neocortex, rather than in the regions mediating control processes responsible for coordinating dual-tasks, in the frontal lobes. Because the former regions are relatively preserved with aging, and access to these representations occurs relatively automatically (i.e. it requires few cognitive resources), older adults show a pattern of interference effects similar to young adults.
**General Discussion.**

I will briefly review the findings of the experiments in this thesis. Next I will discuss other work that supports the notion that representations in the brain, for different types of material, are distinct. I then consider in detail the resource account of DA effects at retrieval, and discuss evidence against this view. The implications of this work with respect to our current understanding of memory decline associated with aging follows. Finally, I discuss the present thesis in relation to current work in neuro-imaging, and propose future studies aimed at specifying the component processes involved in retrieval of episodic memories.

**Summary of Experiments**

Demonstration within a laboratory setting, of a debilitating effect of DA on retrieval has been variable, and sometimes difficult to achieve. These experiments were designed to investigate the unanticipated small, and variable, effects of attentional manipulations on retrieval. Recent work by Fernandes and Moscovitch (2000) showed that a verbal running recognition task and a word-monitoring distracting task, performed concurrently with retrieval, led to an approximate 30% decline in memory performance, from full to DA conditions. These results stand in contrast to other studies of verbal memory in which retrieval was performed concurrently with non-verbal distracting tasks, such as card-sorting (Baddeley et al., 1984), digit-monitoring (Fernandes and Moscovitch, 2000), or a visuo-spatial task (Craik et al., 1996; Naveh-Benjamin et al., 1998), which led to small interference effects on memory. Based on these data, Fernandes and Moscovitch (2000) proposed that recovery of memories is not disrupted by attentional manipulations, but that interference, from DA at retrieval, arises from competition by the distracting task
for common perceptual representations that are activated during recovery of the memory trace.

I initially investigated whether it was necessary to have a memory component in the distracting task to produce interference. All of the verbal distracting tasks from Fernandes and Moscovitch (2000) had a memory load, which left open the possibility that interference effects could potentially be due to competition for memory structures rather than for a common, word-based representational system as they suggested. Despite eliminating the memory component of the distracting task, I found that on-line word-based tasks such as animacy or syllable judgements, performed concurrently with retrieval, produced large interference effects. Furthermore, these effects were not modulated by the level of processing required in the distracting task, whether semantic or phonological. This suggested to me that it was the word-form or phonological aspect of words in the distracting task, rather than their semantic content, that accounted for the large interference effect on memory.

Consistent with this suggestion, Experiments 2 and 3 showed that even a distracting task involving nonsense-words, that has no semantic content, produced comparably large effects on memory. A semantic distracting task involving pictures on the other hand, with no word-form component, produced a significant, but smaller, effect on memory. Increasing the level of difficulty of the picture-based task, from Experiment 2 to Experiment 3, did not increase the size of the interference effect. Thus, to have the largest effect on retrieval, these experiments suggest that the distracting task should engage word-form or phonological processes.

Another important finding from Chapter 2 is that accuracy rate on all of the
distracting tasks suffered under DA conditions at retrieval. Thus, in agreement with Craik et al. (1996), Anderson et al. (1998), Naveh-Benjamin et al. (1998), and Fernandes and Moscovitch (2000), retrieval is not an automatic process, as it draws resources away from the distracting task under DA conditions.

In Chapter 3, I considered an alternate account of the large memory costs from similar material in a distracting task. I investigated whether a reduction in general attentional resources, such as those needed for frontal lobe functions, were responsible for the large effects of DA at retrieval. The results do not support this interpretation. In Experiments 4 and 5, young and old adults were similarly affected by the DA conditions: animacy decisions to words produced much larger disruptions in memory than odd-digit identification as the distracting task. Older adults did not show interference effects on memory that were amplified relative to those observed in young adults, which would be expected based on a resource account.

As in previous studies (Anderson et al., 1998; Macht & Buske, 1983; Nyberg et al., 1997; Park et al., 1989; Whiting & Smith, 1997) DA at retrieval with a non-verbal distracting task did not produce very large effects on memory, and there was no interaction with age. Moreover, if competition for resources accounts for the large effects of DA from word-based distracting tasks, memory interference in participants in Experiment 6 with relatively poor FL function should have been amplified relative to those with better FL function, because they are already compromised in terms of availability of resources.

With respect to costs to the distracting tasks, the results from Chapter 3 are consistent with the conclusion from Chapter 2 that retrieval is not an automatic process,
and does make resource demands, since it produced significant interference on the
distracting tasks when performed concurrently. However, whether these costs are
sensitive to availability of general processing resources, needed for frontal lobe function, is
questionable. If they were, then those with poorer FL function should have shown greater
costs than those with better function, as they would require even greater amounts of
resources to carry out frontal lobe functions. There is some indication, based on the
results of Chapter 2 and 3 of a task-specific component modulating the size of interference
on distracting task performance. That is, similar to the effects on memory, the use of
similar materials in the concurrent tasks produces larger interference on distracting task
performance, compared to when dissimilar materials are used.

However, there are data that argue against a material-specific account of
distracting task costs. First, the size of the costs to the word-animacy and picture-size
tasks from Chapter 2 are similar; based on a material-specific account, one would expect
costs to be greater in the case of word-animacy. What is more, previous work by
Fernandes and Moscovitch (2000) showed that costs did not differ for a word-based
distracting task compared to a digit-based one. Thus material-specificity of the concurrent
tasks may contribute to the size of the distracting task costs, though it does not have as
consistent of an effect as in the case for memory interference.

What do these findings tell us about how retrieval operates? They suggest that
retrieval is not an obligatory process. Performing a word-based task, concurrently with
recall of words, can interfere with reactivation of the neocortical representations necessary
for recovery of the trace. Competition is created as the memory and distracting tasks
compete for the same representational system.
These experiments also allow one to determine more precisely the locus of the DA effect on memory, by specifying what type of representation in the distracting task produces the most interference on the memory task. Because the non-word distracting task, with no semantic content, was shown to disrupt memory, this suggests that phonological or orthographic processing is necessary to retrieve the words from the study list. While it is true that semantic processing in a distracting task, without a word-form component, also interfered with retrieval, it did so to a lesser degree. Thus, competition from a concurrent task for semantic representations is not the primary locus of interference, possibly because semantic representations of target items are more distributed (Martin, Haxby, Lalonde, Wiggs, Cheri et al., 1995) than representations of word forms.

Recently completed work (Moscovitch, Fernandes & Priselac, in preparation) investigated whether word-forms (orthography) were necessary to produce the large effect, or whether picture stimuli could produce the effect, when phonological processing was also required. We found large interference effects, on memory for a word list, when participants simultaneously made phonological decisions (syllable judgements) to Snodgrass and Vanderwort (1980) line drawings. The size of this effect was much larger than that observed from picture-based distracting tasks in Experiments 2 and 3, in which participants made animacy or size judgements about the same pictures. This suggests that the locus of DA effects at retrieval is at the level of phonological representations.

Along the same lines, we found that when the processing required for the distracting task did not require phonological processing, but retained a word-form, the interference effect on memory was minimal. That is, we compared the interference effect
from a task that required odd-digit decisions to numbers that were written, as opposed to
presented in numerical form. Neither of these tasks produced large disruptions on a free
recall test (the decline in memory under both DA conditions was about 10% compared to
full attention conditions).

An alternative account of large effects from DA at retrieval is that prior to output,
words from the study list are held in a short-term memory buffer, or working memory
store. Processing of incoming words for the distracting task may also require working
memory, leading to competition. If we consider this working memory buffer as it was
described by Baddeley and Hitch (1974), it is only verbal-based distracting tasks that
should interfere with recall, whereas spatial-based distracting tasks can be carried out
using the visuo-spatial sketchpad, thereby eliminating any competition for working
memory resources. According to this account, one would expect interference to occur
only when the distracting task requires phonological processing, as this is the code used by
this slave system to process verbal material.

However, there are two pieces of evidence against this interpretation. If
interference arose because the working memory store for verbal material is overextended
under DA conditions with a word-based concurrent task, older adults should have shown
amplified interference effects in this condition. According to Salthouse's (1996) view
aging is associated with a cognitive slowing which reduces the amount and quality of
information simultaneously available in working memory, or the "dynamic capacity" (p.
406) of working memory. Similarly, Hasher and colleagues (Hasher & Zacks, 1991;
Hamm & Hasher, 1992; Hasher, Stoltzfus, Zacks, & Rypma, 1991) suggest older adults
have an impairment in inhibition, leading to a more "cluttered" working memory. Given
these accounts of the state of working memory in older adults, these participants should have been more affected than they were if competition for a verbal working memory buffer underlies the large disruption in memory under DA conditions at retrieval.

What is more, in all but the last experiment, I observed persistent effects of DA, when the distracting task consisted of words or word-forms; once disrupted, very few additional words from the study list could not be recovered, even when the DA session ended. If competition for a verbal working memory system was the locus of interference effects, memory for words from the study list should have recovered. In other work (Fernandes & Moscovitch, in preparation), I tested whether words from the study list were truly unavailable, or simply inaccessible. I gave participants a recognition test following each DA condition, that included all of the words from the study list. Recognition offers more environmental support than free recall (Craik, 1983; 1986; Craik et al., 1996). By providing participants with a powerful external cue (the study word itself), I could determine whether DA interfered with the trace itself (unavailable account), or with the generation of appropriate cues to aid recovery of the trace (inaccessible account). I found that there were more additional words recovered using this test of memory, but that memory did not recover to the level of performance following full attention. Also, participants made more false alarms following the animacy DA condition compared to the odd-digit DA condition. Based on these results, I believe that the memories are largely unavailable following disruption from DA at retrieval. I do acknowledge, however, that an output interference account may apply if participants do not attempt to carry out the animacy and recall task simultaneously, and instead opt for a task-switching strategy, that would allow them to recover from the DA effect.
Although I considered only the verbal-representational system, results from another group found similar material-specific effects of DA at retrieval. Robbins et al. (1996) found that memory retrieval for the arrangement of chess pieces was affected much more by a visuo-spatial concurrent task than a verbal-articulatory task. They did not, however, examine whether there was a recovery of memory following the DA conditions, nor did they examine whether equivalent effects were found in a population of older adults. As such, this study does not allow one to determine whether interference was due to competition for representational systems, in the sense described by the component-process model, or for a common ‘slave’ system in Baddeley and Hitch’s model of working memory.

The lack of a large interference effect on memory from digit-based distracting tasks (Fernandes and Moscovitch, 2000; Experiment 4,5,6 of this thesis) suggests that digits are represented independently from words or word-forms. Consistent with this claim, Allison and colleagues (1994), using electrophysiological recordings, showed a negative potential, N200, in discrete regions of the fusiform and inferior temporal gyri that were in different locations for face, letter-string and number stimuli. This led the authors to conclude that there exists different “modules” for the processing of numbers, in addition to the previous suggestion that there are separate processing streams for faces and words (Farah, 1990, Farah, Wilson, Drain, & Tanaka, 1998). Interestingly, they found no overlap in the location of face and letter-string “modules”, though in some cases letter-string and number N200s were recorded from the same location, which suggested to the authors that these modules may be less functionally and spatially discrete.

The notion of separate modules to handle processing of different types of materials
has also been proposed by McLelland, McNaughton, and O'Reilly (1995). They suggest that the brain undergoes a progressive modularity over time and with increased experience with different types of materials (see also Farah, 1998). This systematic representation of knowledge allows one to process classes of stimuli, such as faces and letters, more efficiently by having certain dedicated regions of specialization. If we consider the results of this thesis in this light, a consequence of such modularity is increased interference when the module is required simultaneously for two tasks. An interesting line of inquiry stemming from this work would be to consider whether young children, who perhaps have not yet developed distinct letter and number modules, show large interference effects under DA at retrieval from both digit and word-based distracting tasks, rather than just from word-based tasks as in adults, who have developed separate modules to represent these materials.

The idea of modular representations is reminiscent of Kinsbourne & Hicks' (1978) suggestion that humans have multi-channel processors and that it is only when the same processors are involved simultaneously in two tasks that performance will be degraded (see also Moscovitch & Klein, 1980; Klein, Moscovitch, & Vigna, 1976). Specifically, Kinsbourne and Hicks proposed that the degree of interference from simultaneous tasks is an inverse function of the “functional distance” between cerebral control centers. Applied to the present work, word, number and picture material may require relatively distinct control centers, thus can be processed independently, leading to little interference under dual-task conditions.

Other work has suggested that memory retrieval cannot be performed under dual-task conditions due to response-selection demands of a secondary (distracting) task.
(Carrier and Pashler, 1995; see also Hartley & Little, 1999). Using the psychological refractory period (PRP) design, their results showed an increase in RT on cued recall and recognition when an auditory-manual two-alternative choice task was concurrently performed. The increase in memory RT indicated that retrieval was postponed by the response selection task, leading them to conclude that retrieval cannot be performed concurrently with another task. While this response selection/retrieval bottleneck may contribute to the magnitude of the interference on memory observed in the present experiments, it is clear that the type of material used for the secondary task also modulates the effect. The picture-based distracting tasks from Experiments 2 and 3 and the odd-digit task from Experiments 4, 5, and 6 led to smaller effects on retrieval than the animacy and non-word tasks. All of these distracting tasks made the same response selection demands. Thus, the type of material in the distracting task is clearly an important factor to consider in understanding memory retrieval.

In addition to reactivation of the memory trace, the component-process model suggests that establishing and maintaining retrieval mode, which may involve monitoring output, is a resource-demanding aspect of retrieval. Under dual-task conditions, this is reflected in costs to the distracting task, regardless of whether material used to divide attention is word-based or visuo-spatial (Fernandes & Moscovitch, 2000). In Experiments 2 and 3, I found that distracting task costs are incurred, regardless of material, under DA conditions with retrieval. Thus, the results are consistent with the proposal that retrieval demands general resources. However, there was considerable variation in the size of these costs to distracting task accuracy. Specifically, in Experiment 4, the animacy task showed greater costs under DA conditions with retrieval than did the
odd-digit task. This occurred despite the fact that the auditory CRT task showed they were equally resource-demanding. It may be that word-based distracting tasks suffered more under DA conditions with retrieval because participants engaged in more monitoring of recall output, and post-ecphoric processing.

The variation in size of distracting task costs, with type of material in Experiment 4, could be interpreted as evidence that word-based distracting tasks have their effect on memory because of competition for attentional resources. This interpretation is in line with Craik’s (1983) proposal that retrieval processes are similar to those involved in perception. For example, there is an increase in RT to search and find a target visual stimulus when it is placed among distractors that share attributes with the target (i.e. color, motion) (Desimone & Duncan, 1995). The increased RT is taken to mean that more attentional resources are need to perform the task in this case relative to when the target is among dissimilar distractors, where the target appears to “pop out” from the distractors without the need for attention. If distracting task costs reflect attentional resources, the increased costs on the animacy task, relative to the odd-digit distracting task suggests that the same phenomenon applies to memory: greater attentional resources are needed to retrieve the target word list when participants are simultaneously processing similar compared to dissimilar materials.

Though I acknowledge that increased competition for attentional resources may contribute somewhat to the large interference effects on memory performance, it cannot be the only source of competition. If it were, older adults in Experiment 4, and the older adults in Experiment 6, classified as having relatively poorer frontal lobe function, would
have shown amplified interference on memory and distracting task performance under
dual-task conditions with animacy distracting task.

In trying to account for the large interference effects of DA at retrieval, from
word-based material, it is worth considering other work in which memory retrieval is
disrupted. In a study by Brown (1968), participants studied 25 of the 50 U.S. states,
followed by a recall attempt of all 50 states. Relative to a control group that did not have
an initial study session, they recalled more of the studied 25 states; but, what is interesting
is that they recalled fewer of the unstudied 25. It appears that study of part of the list of
states had inhibited recall from the complementary subset. This phenomenon is referred to
in the literature as the part-list cueing effect, where the act of retrieval inhibits recall of
information that is associated with the successfully retrieved target information (Roediger,

In more recent work, Anderson, Bjork and Bjork (1994) asked participants to
practice retrieving half of the items from each of several categories. In an ensuing
retrieval session, in which all items from the categories were to be recalled, they found
that recall of non-practiced items was inhibited relative to a control condition. The
authors explain this effect in terms or inhibition or suppression of unpracticed items during
the retrieval practice session that persists to the subsequent retrieval session. Thus,
retrieval in part-list cueing experiments acts to facilitate the recall of target items by
suppressing associated, but non-target items. An interesting future study would be to
investigate whether even greater interference effects would be found when the study list
contained related, versus unrelated words; if there is a common underlying process
between the large memory effects observed in this thesis under DA, and the part-list cueing effect, retrieval may inhibited more for the list of highly associated words.

While the part-list cueing effect has been observed for memory of well-learned, semantic information, and categorized word lists, the means by which retrieval fails may be related to the interference effects observed in this thesis, for a list of unrelated words. For example, in almost all of my experiments, the interference effect on memory persisted, even when the dual-task condition ended; in general, participants were unable to recall additional words from the study list, at the completion of the DA session. It may be that under DA conditions with word-based distracting tasks, recall of target words was possible only by suppressing the similar, distracting task items. Whatever the neural mechanism for this suppression, it may have extended to whichever target words were not recalled during the DA condition. This would account for the persistent effects of DA on memory. This also suggests that when retrieval occurs under conditions in which one is faced with having to simultaneously process similar materials, some amount of suppression might be necessary in order to recall any items.

Insofar as the processing of similar materials is concerned, theories aimed at understanding selection of target items among distractors are important to consider. Rather than subscribe to a suppression account of selection, LaBerge (1997) suggests that attention to target information is enhanced, via top-down influences from the PFC. These function to enhance cortical columns in the posterior parietal cortex (PPC), which represent the "object" of attention, by the action of the thalamus, which specifies the intensity of activation of neurons in the PPC. In the absence of supporting signals from the PFC, activation in PPC decays. In the case of this thesis, the "object" may be words
from the study list. Applying these ideas to memory retrieval, once in retrieval mode, the PFC may act to enhance the representations of words, stored in the PPC. Under DA conditions with word-based distractors, the selection of columns to enhance may be impaired, or the level of enhancement reduced, as attention must also be directed to the distracting task. Retrieval under DA using dissimilar material is not subject to these impairments as items from the target word list may be subject to a preattentive "pop out" effect (Treisman & Gelade, 1980). The drawback of this account however, is that it places the locus of the interference effect with a homunculus in the PFC, whose role is in parceling out attentional resources. Also, as already discussed in Chapter 3, and in the previous section relating memory to perception, the lack of amplified effects in older adults and those with poor frontal function are inconsistent with this account.

A further line of inquiry stemming from the component process model involves showing that the material-specific effects of DA at retrieval apply to other tests of memory. In this thesis I considered only free recall tests of memory. According to the model, if effects arise from competition for perceptual representation responsible for the content of the memory, then the material specific effects reported here should also be observed on recognition, and even on perceptual implicit tests of memory.

With respect to recognition tests, I have conducted some preliminary investigations, and the results are in line with the component-process model (Fernandes & Moscovitch, in preparation b). Recognition tests offer more "environmental support" than recall tests of memory: an external cue (the word itself) can be used to aid retrieval, in contrast to free recall, in which internal cue generation is needed. (Craik et al., 1996; Anderson et al., 1998). Along the same lines, recognition may be driven more by
familiarity-based processes and less so by control (conscious) processes (Jacoby, 1991). If word-based distracting tasks interfere with internal cue-generation, then we should see less interference when a recognition task is used, since recognition offers external cues to guide retrieval. Also, recognition relies more heavily on inferior parietal activations compared to recall, which relies more on cerebellar-frontal pathway activation, believed to reflect the initiation of cue-generation needed for free recall (Cabeza et al., 1997). If DA at retrieval interfered with cerebellar-frontal activation, then performance on a recognition test, which does not rely as heavily on this circuit, would not be affected under DA with word-based distracting tasks. The component-process model places the locus of interference at the level of perceptual representations, and predicts that recognition would be impaired, as is free recall, though to a lesser extent since recognition is an easier test of memory.

In line with the component-process model, I found recognition performance, measured as hit rate – false alarm rate was .82 under full attention, .75 under DA conditions with an odd-digit task, and .66 under DA conditions with an animacy task. These results show that interference effects from word-based distracting tasks are not due to impaired generation, or strategic search for responses since the effect is maintained even with a recognition test of memory. I also considered whether the poorer performance under DA conditions with the animacy task was due to an increased susceptibility to false alarms, but this was not the case. The hit rate was 0.84 under full attention, 0.78 and 0.69 in the DA condition with the odd-digit and animacy tasks respectively. Analysis showed that the hit rate and false alarm rate did not differ across
these conditions. Thus, impaired cue-generation, or poorer discrimination of study words, cannot account for the material-specific interference effect.

If interference occurs for perceptual representations, as suggested by the model, one would expect to see material-specific interference effects even on perceptual implicit tests of memory. Like recognition, perceptual implicit tests do not require generation of internal cues to guide retrieval. DA at retrieval using a word-based distracting task may disrupt the representation of words in memory, and produce interference even on such implicit tests since these rely heavily on perceptual systems.

In addition to considering other tests of memory, the component-process model can be further evaluated using neuroimaging. Several studies have shown activations during retrieval in right prefrontal (BA10) and subcortical areas including putamen, globus pallidus, and thalamus, as well as in the posterior cingulate, cuneus, and cerebellum (Cabeza & Nyberg, 1997; Tulving et al., 1994, lidaka , Anderson, Kapur, Cabeza, & Craik, 2000). Interestingly, areas of decreased activation were also noted in a neuroimaging study of DA effects on retrieval, in bilateral temporal regions extending to the insula cortex (lidaka et al., 2000). This bitemporal negativity, in DA compared to full attention conditions, was also seen in neuroimaging studies of visual attention (Corbetta et al., 1991), and short-term memory (Andreason et al., 1995). This negativity has been interpreted as task-related inhibition from other brain regions, to prevent processing of irrelevant material (Grasby et al., 1993; Nyberg et al., 1996; Raichle et al., 1994).

This proposition brings up the possibility of an alternative locus for the large DA effects observed in this thesis; the MTL may contribute to the interference effect from DA using word-based distracting tasks. It is possible that the network pattern of brain activity
is quite different under DA conditions with similar versus non-similar distractors: with increased similarity of dual-tasks, perhaps there is more inhibition in MTL/H regions, a by-product of trying to prevent processing of non-relevant material. This possibility would be useful to investigate in the future. The component-process model suggests that interference can occur at the level of the MTL/H or the posterior neocortex. On the basis of the experiments in this thesis, and those in Fernandes and Moscovitch (2000), I favor the neocortex interpretation rather than a MTL/H locus for the effect. Thus I expect that interference arises from competition in posterior regions responsible for the content of memory traces, likely in parietal and/or precuneus regions.
References


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Appendix 1.1

Experiment 1 Instructions to Participants and Experimenter's tasks

PRACTICE PHASE

All Participants must have normal or corrected to normal vision and hearing, as well as be native English speakers

You're going to be doing a dual-task experiment, which means that you will be doing two different tasks at the same time. I'll show you the two tasks separately first, then we'll combine them. We'll start with the recall memory task.

I'm going to turn on the tape, and you will hear a female voice read 16 different words, one at a time. I want you to try to remember the words.

Just to let you know how the tape is set up: Three beeps will signal the beginning of the list and three beeps will also be played at the end of the list. Following this, a number (like 210), will be spoken and I want you to start counting backwards out loud by threes from that number. You will do this for 15 seconds, until I tell you to stop.

Then, I will tell you to start recalling out loud as many of the 16 taped words as you can. You can recall the words in any order. You will have one minute for this recall memory task; Is everything clear? Do you have any questions about what you are suppose to do? I will remind you about what you have to do before each task.

Play tape with practice words for recall task

Stop counting backwards. Begin recalling words from the tape NOW:

Prepare cassette to record recall memory task

Hit space bar on computer to start one minute timer;
also hit record on cassette (allows accuracy check on words recalled)

Very good. Now you will do an identification task. In this task, a list of words will be presented on the screen, one at a time. Some of the words in the list will represent 'animals' and some will be of 'man-made objects'. Your task is to hit the silver key whenever a man-made word is presented on the screen. Always keep your index finger on the key so you can make your response as soon as you notice a word is man-made. The computer won't wait for you to make a response. It's up to you to identify the man-made words, and we'll be checking your accuracy rate. ALSO…
Part-way through the experiment a buzz will sound. This is just to familiarize you with the sound as it will be used in the experimental phase. Remember, your task is to hit the silver key to indentify when a MAN-MADE word is presented to you.

Hit space bar to begin MAN-MADE distracting task practice;
Make sure subject performs accurately

Very good. Now you’ll get a practice session on a slightly different task. Rather than seeing a list of animal and man-made words, you’ll see a list of 1, 2 and 3 syllable words. For example, love, hammer and barbeque are examples of 1, 2 and 3 syllable words. Your task is to hit the silver key whenever a 2-syllable word is presented on the screen. Always keep your index finger on the key so you can make your response as soon as you notice a word is 2-syllables. Are you clear on what you have to do?? (make sure they understand what syllables are). Again we’ll be checking your accuracy rate. And, again, Part-way through the experiment a beep will sound. As before, this is just to familiarize you with the sound as it will be used in the experimental phase.

Hit space bar to begin 2-syllable distracting task practice;
Make sure subject performs accurately

Baseline distracting task “MAN-MADE/2-syllable” version

Check which baseline distracting task they do first (see order sheet)

The experimental phase will now begin. I want you to know that for each session, brand new sets of words will be used. Now, I want to find out how accurate you are at the MAN-MADE/2-syllable task. We never collect data during practice sessions since we understand you’re just getting used to the tasks. Now that you know what to do, I need to collect some data. Essentially your task is the same as what you just finished doing in the practice sessions, only this time I’ll assume you know what you’re doing and collect data.

Hit space bar begin BASELINE repeat

Well done. We’ll now move on to the next task.
Man-made identification as the distracting task

Now comes the dual-task part of the experiment. I'll let you listen to a new set of words on the tape, then test your memory for the words. BUT, you will have to try to recall the words from the tape while SIMULTANEOUSLY doing the man-made task on the computer. I'LL READ YOU AN OVERVIEW OF WHAT YOU HAVE TO DO, SO THAT YOU HAVE A GENERAL IDEA OF WHAT'S GOING TO HAPPEN.

Shortly I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

THEN, you will go to the computer and start the MAN-MADE test, hitting the silver key whenever you notice a man-made word is presented to you. You will continue to perform the man-made test ALONE, until you hear the buzzing sound. This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, this is a dual-task experiment, so you MUST CONTINUE DOING THE MAN-MADE TEST WHILE SIMULTANEOUSLY TRYING TO RECALL WORDS FROM THE TAPE.

It is VERY important that you continue to do the MAN-MADE task WHILE you are trying to recall the words from the tape. You should place a 50/50 emphasis on each task.

Any questions? We will now begin. I will play the tape, and you should try to commit as many words to memory as you can.

Play word list

After 15 seconds of counting backwards, hit spacebar to begin MAN-MADE task

START tape-recorder at BUZZ CUE !!!!!

REMIND Participants to keep doing man-made task while recalling words

Well done, now take a break so you are ready for more when we get back.

Give 4 minute break in lounge
Baseline Recall

AGAIN, I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

THEN, you will go to the computer and start the MAN-MADE/2-syllable test, hitting the silver key whenever you notice a man-made/2-syllable word is presented to you. You will continue to perform the test ALONE, until you hear the buzzing sound.

This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, your ONLY task after the BUZZ sound will be to RECALL WORDS FROM THE TAPE. That is, the MAN-MADE/2-syllable task will end, the screen will go blank once the BUZZ sound is heard. YOU SHOULD FOCUS ALL OF YOUR ATTENTION ON RECALLING AS MANY WORDS FROM THE TAPE AS YOU CAN.

Any questions? We will now begin. I will play the tape, and you should try to commit as many words to memory as you can.

Play word list

After 15 seconds of counting backwards, hit spacebar to begin MAN-MADE/2-syllable task

START tape-recorder at BUZZ CUE !!!!!

Well done, now take a break so you are ready for more when we get back.

Give 4 minute break in lounge

‘2-syllable’ identification as the distracting task

Now comes the dual-task part of the experiment. I’ll let you listen to a new set of words on the tape, then test your memory for the words. BUT, you will have to try to recall the words from the tape while SIMULTANEOUSLY doing the 2-syllable task on the computer. I’LL READ YOU AN OVERVIEW OF WHAT YOU HAVE TO DO, SO THAT YOU HAVE A GENERAL IDEA OF WHAT’S GOING TO HAPPEN.
Shortly I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

**THEN,** you will go to the computer and start the 2-syllable test, hitting the silver key whenever you notice a 2-syllable word is presented to you. You will continue to perform the 2-syllable test ALONE, until you hear the buzzing sound. This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, this is a dual-task experiment, so you **MUST CONTINUE DOING THE 2-syllable TEST WHILE SIMULTANEOUSLY TRYING TO RECALL WORDS FROM THE TAPE.**

It is VERY important that you continue to do the 2-syllable task **WHILE** you are trying to recall the words from the tape. You should place a 50/50 emphasis on each **task.**

Any questions? We will now begin. I will play the tape, and you should try to commit as many words to memory as you can.

\[Play \text{ word list}\]

\[After \ 15 \ seconds \ of \ counting \ backwards, \ hit \ spacebar \ to begin \ 2\text{-syllable} \ task\]

\[START \ tape-recorder \ at \ BUZZ \ CUE \ !!!!!\]

REMINd Participants to keep doing 2-syllable task while recalling words

Well done, now take a break so you are ready for more when we get back.

Give 4 minute break in lounge

**Baseline distracting task –**MAN-MADE OR 2-syllable version

Check which baseline distracting task they do LAST (see schedule)

\[AS \ was \ done \ at \ the \ beginning \ of \ the \ experimental \ phase, \ I \ now \ want \ to \ find \ out \ how \ accurate \ you \ are \ at \ the \ MAN-MADE/2-syllable \ task. \ We \ never \ collect \ data \ during \ practice\]
sessions since we understand you’re just getting used to the tasks. Now I need to collect some data. Essentially your task is the same as what you just finished doing in the practice and experimental sessions, only this time I’ll collect data on your accuracy, so I can compare it with dual-task performance.

Ignore the BEEP TONE that will be heard part-way through.

Hit space bar begin BASELINE repeat

Well done.
I have one more task I want to test you on, and it’ll take about 6-7 more minutes.

GO TO tone TASK USING BOTH COMPUTERS.

EXPLAIN TASK ONCE COMPUTERS ARE SET UP.

You will now be doing something completely different from what you just finished doing, it involves listening to and identifying tones that you hear coming from the computer speakers.

Read instructions from screen.
Point out that tones will be heard from speakers

Your 3 fingers should always be on the keys so that you can make your response as quickly and as accurately as possible. As soon as you hit a key to identify it, the next tone will come on, and you must respond right away. As such, this is a CONTINUOUS task since you’ll always be identifying a tone.

The task lasts for 2 minutes (1:55 actually) so try to stay focused.

Start timer at SAME TIME as subject hits one of the keys to start the program. Hit THEIR spacebar to end tones after 1 minute 55 seconds

GREAT

Set up experiment again with same subject number BUT different session number.

Now I’ll have you do the tone test all over again, but this time, after about 15 seconds of doing the tone task alone, I’ll start the program for the MAN-MADE/2-SYLLABLE TEST (odd subject #: man-made then 2-syllable; even subject #: 2-syllable then man-made).

You’ll have to say ‘YES’ out loud whenever you see a MAN-MADE/2-SYLLABLE word presented to you, and I will hit the silver key for you over here on this keyboard.

SO, you must continue to do the tone task while simultaneously identifying MAN-MADE\2-SYLLABLE words from the screen. Are you clear on what you have to do??
Start timer as soon as subject hits key to start tones.  
After 15 seconds hit YOUR SPACEBAR to start MAN-MADE/2-SYLLABLE task

Remind subject which task they are doing MAN-MADE OR 2-SYLLABLE (ODD # man-made then 2-syllable, EVEN # 2-syllable then man-made)

Set up experiment again with same subject number BUT different session number.

Almost done

Now I'll have you do the tone test all over again, but this time, after about 15 seconds of doing the tone task alone, I'll start the program for the MAN-MADE/2-SYLLABLE TEST (odd subject #: man-made then 2-syllable; even subject #: 2-syllable then man-made).

As before, You'll have to say 'YES' out loud whenever you see a MAN-MADE/2-SYLLABLE word presented to you, and I will hit the silver key for you over here on this keyboard.

SO, you must continue to do the tone task while simultaneously identifying MAN-MADE/2-SYLLABLE words from the screen. Are you clear on what you have to do??

Start timer as soon as subject hits key to start tones.  
After 15 seconds hit YOUR SPACEBAR to start MAN-MADE/2-SYLLABLE task

Remind subject which task they are doing MAN-MADE OR 2-SYLLABLE (ODD # man-made then 2-syllable, EVEN # 2-syllable then man-made)
Appendix 1.2

Experiment 2 Instructions to Participants and Experimenter's tasks

PRACTICE PHASE

*All Participants must have normal or corrected to normal vision and hearing, as well as be native English speakers*

You’re going to be doing a dual-task experiment, which means that you will be doing two different tasks at the same time. I’ll show you the two tasks separately first, then we’ll combine them. We’ll start with the recall memory task.

I’m going to turn on the tape, and you will hear a female voice read 16 different words, one at a time. I want you to try to remember the words.

Just to let you know how the tape is set up:
Three beeps will signal the beginning of the list and three beeps will also be played at the end of the list. Following this, a number (like 210), will be spoken and I want you to start counting backwards out loud by threes from that number. You will do this for 15 seconds, until I tell you to stop.

Then, I will tell you to start recalling out loud as many of the 16 taped words as you can. You can recall the words in any order. You will have one minute for this recall memory task. Is everything clear? Do you have any questions about what you are suppose to do? I will remind you about what you have to do before each task.

*Play tape with practice words for recall task*

Stop counting backwards. Begin recalling words from the tape NOW:

*Prepare cassette to record recall memory task*

Hit space bar on computer to start one minute timer;
also hit record on cassette (allows accuracy check on words recalled)

Very good. Now you will do an identification task. In this task, a string of pictures will be presented on the screen, one at a time. Some represent living things and others represent man-made items. Your task is to hit the green key whenever you see a picture that represents a man-made item.
Always keep your index finger on the key so you can make your response as soon decide if the picture is of a man-made item. The computer won’t wait for you to make a response, so have your finger ready to press the key at all times. ALSO…

Part-way through the experiment a buzz will sound. This is just to familiarize you with the sound as it will be used in the experimental phase.

*Hit space bar to begin PICTURE animacy practice*

*Make sure subject performs accurately*

Very good. Now you’ll get a practice session on a slightly different task. Rather than seeing a string of pictures, you’ll see a list of 1, 2 and 3 syllable pronounceable non-words. That is, the letter strings you’ll see on the screen do not make up an actual word, but you will be able to sound it out to yourself since the non-words are made to look and sound like real words.

For example,

bove
hammet
jarbeque

are examples of 1, 2, and 3 syllable non-words. Your task is to hit the green key whenever a 2-syllable non-word is presented on the screen. Always have your finger on the green key so you can make your response as soon decide if it is a 2-syllable non-word. The computer won’t wait for you to make a response, so have your finger ready to press the key at all times.

And, again, Part-way through the experiment a beep will sound. As before, this is just to familiarize you with the sound as it will be used in the experimental phase.

*Hit space bar to begin 2-syllable non-word practice*

*Make sure subject performs accurately*

**Baseline distracting task PICTURE animacy/2-syllable version**

Check which baseline distracting task they do first (see schedule)

The experimental phase will now begin. I want you to know that for each session, brand new sets of words will be used. Now, I want to find out how accurate you are at the PICTURE animacy/2-syllable task. We never collect data during practice sessions since we understand you’re just getting used to the tasks. Essentially your task is the same as what
you just finished doing in the practice sessions, only this time I'll assume you know what you're doing and collect data.

*Hit space bar begin BASELINE repeat*

Well done. We'll now move on to the next task.
**Picture animacy as the distracting task**

Now comes the dual-task part of the experiment. I'll let you listen to a new set of words on the tape, then test your memory for the words. BUT, you will have to try to recall the words from the tape while SIMULTANEOUSLY doing the picture animacy task on the computer. I'LL READ YOU AN OVERVIEW OF WHAT YOU HAVE TO DO, SO THAT YOU HAVE A GENERAL IDEA OF WHAT’S GOING TO HAPPEN.

Shortly I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

THEN, you will go to the computer and start the PICTURE animacy test, hitting the green key whenever you notice a picture that represents a man-made item. You will continue to perform the picture test ALONE, until you hear the buzzing sound.

This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, this is a dual-task experiment, so you MUST CONTINUE DOING THE PICTURE animacy TEST WHILE SIMULTANEOUSLY TRYING TO RECALL WORDS FROM THE TAPE.

It is VERY important that you continue to do the PICTURE task WHILE you are trying to recall the words from the tape. **You should place a 50/50 emphasis on each task.**

**Play word list**

After 15 seconds of counting backwards, hit spacebar to begin PICTURE SIZE task

START tape-recorder at BUZZ CUE !!!!!

REMIND Participants to keep doing picture task while recalling words

Well done, now take a break so you are ready for more when we get back.

Give 4 minute break in lounge
Baseline Recall

AGAIN, I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

THEN, you will go to the computer and start the PICTURE animacy/2-syllable test, hitting the green key whenever you notice a picture of a man-made item /2-syllable non-word is presented to you. You will continue to perform the test ALONE, until you hear the buzzing sound.

This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, your ONLY task after the BUZZ sound will be to RECALL WORDS FROM THE TAPE. That is, the PICTURE animacy/2-syllable non-word task will end, the screen will go blank once the BUZZ sound is heard. YOU SHOULD FOCUS ALL OF YOUR ATTENTION ON RECALLING AS MANY WORDS FROM THE TAPE AS YOU CAN.

Any questions? We will now begin. I will play the tape, and you should try to commit as many words to memory as you can.

**Play word list**

*After 15 seconds of counting backwards, hit spacebar to begin PICTURE animacy /2-syllable task*

*START tape-recorder at BUZZ CUE!!!!!*

Well done, now take a break so you are ready for more when we get back.

Give 4 minute break in lounge

‘2-syllable non-word’ identification as the distracting task

Now comes the dual-task part of the experiment. I’ll let you listen to a new set of words on the tape, then test your memory for the words. BUT, you will have to try to recall the words from the tape while SIMULTANEOUSLY doing the 2-syllable non-word task on the computer. I’LL READ YOU AN OVERVIEW OF WHAT YOU HAVE TO DO, SO THAT YOU HAVE A GENERAL IDEA OF WHAT’S GOING TO HAPPEN.
Shortly I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

THEN, you will go to the computer and start the 2-syllable non-word test, hitting the green key whenever you notice a 2-syllable non-word is presented to you. You will continue to perform the test ALONE, until you hear the buzzing sound. This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, this is a dual-task experiment, so you MUST CONTINUE DOING THE 2-syllable TEST WHILE SIMULTANEOUSLY TRYING TO RECALL WORDS FROM THE TAPE.

It is VERY important that you continue to do the 2-syllable task WHILE you are trying to recall the words from the tape. You should place a 50/50 emphasis on each task.

Any questions? We will now begin. I will play the tape, and you should try to commit as many words to memory as you can.

**Play word list**

*After 15 seconds of counting backwards, hit spacebar to begin 2-syllable task*

*START tape-recorder at BUZZ CUE !!!!!*

REMIND Participants to keep doing 2-syllable task while recalling words

Well done, now take a break so you are ready for more when we get back.

Give 4 minute break in lounge

**Baseline distracting task—PICTURE animacy OR 2-syllable non-word version**

Check which baseline distracting task they do LAST (see schedule)

AS was done at the beginning of the experimental phase, I now want to find out how accurate you are at the PICTURE animacy /2-syllable task. We never collect data during
practice sessions since we understand you're just getting used to the tasks. Essentially your
task is the same as what you just finished doing in the practice and experimental sessions,
only this time I'll collect data on your accuracy, so I can compare it with dual-task
performance.

Ignore the BUZZ TONE that will be heard part-way through.

*Hit space bar begin BASELINE repeat*

Well done.
Appendix 1.3

Experiment 3 Instructions to Participants and Experimenter's tasks

**PRACTICE PHASE**

*All Participants must have normal or corrected to normal vision and hearing, as well as be native English speakers*

You're going to be doing a dual-task experiment, which means that you will be doing two different tasks at the same time. I'll show you the two tasks separately first, then we'll combine them. We'll start with the recall memory task.

I'm going to turn on the tape, and you will hear a female voice read 16 different words, one at a time. I want you to try to remember the words.

Just to let you know how the tape is set up: Three beeps will signal the beginning of the list and three beeps will also be played at the end of the list. Following this, a number (like 210), will be spoken and I want you to start counting backwards out loud by threes from that number. You will do this for 15 seconds, until I tell you to stop.

Then, I will tell you to start recalling out loud as many of the 16 taped words as you can. You can recall the words in any order. You will have one minute for this recall memory task; Is everything clear? Do you have any questions about what you are supposed to do? I will remind you about what you have to do before each task.

*Play tape with practice words for recall task*

Stop counting backwards. Begin recalling words from the tape NOW:

*Prepare cassette to record recall memory task*

*Hit space bar on computer to start one minute timer; also hit record on cassette (allows accuracy check on words recalled)*

Very good. Now you will do an identification task. In this task, a string of pictures will be presented on the screen, one at a time. Your task is to hit the green key whenever you see a picture that represents an item that is BIGGER THAN AN AVERAGE COMPUTER MONITOR.

Always keep your index finger on the key so you can make your response as soon decide if it is BIGGER THAN AN AVERAGE SIZED MONITOR. The computer won't wait for you to make a response, so have your finger ready to press the key at all times. ALSO...
Part-way through the experiment a buzz will sound. This is just to familiarize you with the sound as it will be used in the experimental phase.

*Hit space bar to begin PICTURE SIZE practice;*
*Make sure subject performs accurately*

Very good. Now you’ll get a practice session on a slightly different task. Rather than seeing a string of pictures, you’ll see a list of 1, 2 and 3 syllable pronounceable non-words. That is, the letter strings you’ll see on the screen do not make up an actual word, but you will be able to sound it out to yourself since the non-words are made to look and sound like real words.

For example,

- bove
- hammet
- jarbeque

are examples of 1, 2, and 3 syllable non-words. Your task is to hit the green key whenever a 2-syllable non-word is presented on the screen. Always have your finger on the green key so you can make your response as soon decide if it is a 2-syllable non-word. The computer won’t wait for you to make a response, so have your finger ready to press the key at all times.

And, again, Part-way through the experiment a beep will sound. As before, this is just to familiarize you with the sound as it will be used in the experimental phase.

*Hit space bar to begin 2-syllable non-word practice;*
*Make sure subject performs accurately*

**Baseline distracting task PICTURE SIZE/2-syllable” version**

**Check which baseline distracting task they do first (see schedule)**

The experimental phase will now begin. I want you to know that for each session, brand new sets of words will be used. Now, I want to find out how accurate you are at the PICTURE SIZE/2-syllable task. We never collect data during practice sessions since we understand you’re just getting used to the tasks. Essentially your task is the same as what you just finished doing in the practice sessions, only this time I’ll assume you know what you’re doing and collect data.

*Hit space bar begin BASELINE repeat*

Well done. We’ll now move on to the next task.
**Picture size identification as the distracting task**

Now comes the dual-task part of the experiment. I’ll let you listen to a new set of words on the tape, then test your memory for the words. BUT, you will have to try to recall the words from the tape while SIMULTANEOUSLY doing the picture size task on the computer. I’LL READ YOU AN OVERVIEW OF WHAT YOU HAVE TO DO, SO THAT YOU HAVE A GENERAL IDEA OF WHAT’S GOING TO HAPPEN.

Shortly I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

THEN, you will go to the computer and start the PICTURE SIZE test, hitting the green key whenever you notice a picture that represents an item that is BIGGER THAN AN AVERAGE COMPUTER MONITOR. You will continue to perform the picture size test ALONE, until you hear the buzzing sound.

This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, this is a dual-task experiment, so you MUST CONTINUE DOING THE PICTURE SIZE TEST WHILE SIMULTANEOUSLY TRYING TO RECALL WORDS FROM THE TAPE.

It is VERY important that you continue to do the PICTURE SIZE task WHILE you are trying to recall the words from the tape. **You should place a 50/50 emphasis on each task.**

**Play word list**

*After 15 seconds of counting backwards, hit spacebar to begin PICTURE SIZE task*

*START tape-recorder at BUZZ CUE !!!!!*

REMIND Participants to keep doing picture size task while recalling words

Well done, now take a break so you are ready for more when we get back.

Give 4 minute break in lounge
Baseline Recall

AGAIN, I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

THEN, you will go to the computer and start the PICTURE SIZE/2-syllable test, hitting the green key whenever you notice a picture bigger than a monitor/2-syllable non-word is presented to you. You will continue to perform the test ALONE, until you hear the buzzing sound.

This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, your ONLY task after the BUZZ sound will be to RECALL WORDS FROM THE TAPE. That is, the PICTURE SIZE/2-syllable non-word task will end, the screen will go blank once the BUZZ sound is heard. YOU SHOULD FOCUS ALL OF YOUR ATTENTION ON RECALLING AS MANY WORDS FROM THE TAPE AS YOU CAN.

Any questions? We will now begin. I will play the tape, and you should try to commit as many words to memory as you can.

Play word list

After 15 seconds of counting backwards, hit spacebar to begin PICTURE SIZE/2-syllable task

START tape-recorder at BUZZ CUE !!!!!

Well done, now take a break so you are ready for more when we get back.

Give 4 minute break in lounge

‘2-syllable non-word’ identification as the distracting task

Now comes the dual-task part of the experiment. I’ll let you listen to a new set of words on the tape, then test your memory for the words. BUT, you will have to try to recall the words from the tape while SIMULTANEOUSLY doing the 2-syllable non-word task on the computer. I’LL READ YOU AN OVERVIEW OF WHAT YOU HAVE TO DO, SO THAT YOU HAVE A GENERAL IDEA OF WHAT’S GOING TO HAPPEN.
 Shortly I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

THEN, you will go to the computer and start the 2-syllable non-word test, hitting the green key whenever you notice a 2-syllable non-word is presented to you. You will continue to perform the test ALONE, until you hear the buzzing sound. This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, this is a dual-task experiment, so you MUST CONTINUE DOING THE 2-syllable TEST WHILE SIMULTANEOUSLY TRYING TO RECALL WORDS FROM THE TAPE.

It is VERY important that you continue to do the 2-syllable task WHILE you are trying to recall the words from the tape. You should place a 50/50 emphasis on each task.

Any questions? We will now begin. I will play the tape, and you should try to commit as many words to memory as you can.

*Play word list*

*After 15 seconds of counting backwards, hit spacebar to begin 2-syllable task*

*START tape-recorder at BUZZ CUE !!!!!

REMIND Participants to keep doing 2-syllable task while recalling words

Well done, now take a break so you are ready for more when we get back.

Give 4 minute break in lounge

*Baseline distracting task – PICTURE SIZE OR 2-syllable non-word version*

Check which baseline distracting task they do LAST (see schedule)

AS was done at the beginning of the experimental phase, I now want to find out how accurate you are at the PICTURE SIZE/2-syllable task. We never collect data during
practice sessions since we understand you’re just getting used to the tasks. Essentially your task is the same as what you just finished doing in the practice and experimental sessions, only this time I’ll collect data on your accuracy, so I can compare it with dual-task performance.

Ignore the BUZZ TONE that will be heard part-way through.

*Hit space bar begin BASELINE repeat*

Well done.
Appendix 1.4

Experiment 4, 5, and 6 Instructions to Participants and Experimenter's tasks

PRACTICE PHASE

All Participants must have normal or corrected to normal vision and hearing, as well as be native English speakers.

You’re going to be doing a dual-task experiment, which means that you will be doing two different tasks at the same time. I’ll show you the two tasks separately first, then we’ll combine them. We’ll start with the recall memory task.

I’m going to turn on the tape, and you will hear a female voice read 16 different words, one at a time, very slowly. I want you to try to remember these words.

Just to let you know how the tape is set up:
Three beeps will signal the beginning of the list and three beeps will also be played at the end of the list. Following this, a number (like 210), will be spoken and I want you to start counting backwards out loud by threes from that number. You will do this for 15 seconds, until I tell you to stop.

Then, I will tell you to start recalling out loud as many of the 16 taped words as you can. You can recall the words in any order. You will have one minute for this recall memory task.

Is everything clear? I will remind you about what you have to do before each task.

Play tape with practice words for recall task

Stop counting backwards. Begin recalling words from the tape NOW:

Record recall onto cassette

Hit space bar on computer to start one minute timer; also hit record on cassette (allows accuracy check on words recalled)

Very good. Now you will do a different task.

In this task, a list of words will be presented on the screen, one at a time. Some of the words in the list will represent ‘animals’ and some will be of ‘man-made objects’. Your task is to hit the green key whenever a man-made word is presented on the screen. Always keep your index finger on the key so you can make your response as soon as you notice a word is man-made. The computer won’t wait for you to make a response. It’s up
to you to identify the man-made words, and we'll be checking your accuracy rate.

ALSO...

Part-way through the experiment a buzz will sound. This is just to familiarize
you with the sound as it will be used in the experimental phase. Remember, your task is to
hit the green key to identify when a MAN-MADE word is presented to you.

Hit space bar to begin MAN-MADE distracting task practice;
Make sure subject performs accurately

Very good. Now you’ll get a practice session on a slightly different task. Rather
than seeing a list of animal and man-made words, you’ll see a list of 2-digit numbers. Some
of the numbers will be even, ending in 0, 2, 4, 6, or 8 and some will be odd, ending in 1, 3,
5, 7, or 9.

Your task is to hit the green key whenever an odd-digit is presented on the screen.
Always keep your index finger on the key so you can make your response as soon as you
notice an odd-digit.

Again we’ll be checking your accuracy rate. And, again, Part-way through the
experiment a beep will sound. As before, this is just to familiarize you with the sound as
it will be used in the experimental phase.

Hit space bar to begin odd-digit distracting task practice;
Make sure subject performs accurately

EXPERIMENTAL PHASE

Instructions for:

Baseline (single-task) "MAN-MADE (or odd-digit)" measure
Check which single-task baseline they do first (see order sheet)

The experimental phase will now begin. I want you to know that for each session,
brand new sets of words will be used. Now I want to find out how accurate you are at the
MAN-MADE (or ODD-DIGIT) task.

We don’t collect data during practice sessions since we understand you’re just
getting used to the tasks. Now that you know what to do, I need to collect some data.
Essentially your task is the same as what you just finished doing in the practice sessions,
only this time I’ll collect data.

Hit space bar to begin single-task BASELINE

Well done. We’ll now move on to the next task.
Instructions for:

**Man-made identification as the distracting task**

Now comes the dual-task part of the experiment. I'll let you listen to a new set of words on the tape, then test your memory for the words.

BUT, you will have to try to recall the words from the tape while SIMULTANEOUSLY doing the man-made task on the computer. I'LL READ YOU AN OVERVIEW OF WHAT YOU HAVE TO DO, SO THAT YOU HAVE A GENERAL IDEA OF WHAT'S GOING TO HAPPEN.

Shortly I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

THEN, you will go to the computer and start the MAN-MADE test, hitting the green key whenever you notice a man-made word is presented to you. You will continue to perform the man-made test ALONE, until you hear the buzzing sound. This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, this is a dual-task experiment, so you MUST CONTINUE DOING THE MAN-MADE TEST WHILE SIMULTANEOUSLY TRYING TO RECALL WORDS FROM THE TAPE.

It is VERY important that you continue to do the MAN-MADE task WHILE you are trying to recall the words from the tape. **You should place a 50/50 emphasis on each task.**

Any questions?

*Play study word list*

*After 15 seconds of counting backwards, hit spacebar to begin MAN-MADE task*

**START tape-recorder at BUZZ CUE !!!!!**

**REMIND Participants to keep doing man-made task while recalling words**

*Once the divided attention session is complete ask:*

Now that you don’t have to do two things at the same time, can you recall any more words from the study list?

Well done, now take a break so you are ready for more when we get back.

Give 5 minute break
Instructions for:

**Full Attention during recall**

AGAIN, I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

THEN, you will go to the computer and start the (see order sheet: if verbm, task here is 'man-made'; if verbnu, task here is ‘odd-digit’) MAN-MADE (or odd-digit) test, hitting the green key whenever you notice a ‘man-made’ word (or odd-digit) is presented to you. You will continue to perform the test ALONE, until you hear the buzzing sound.

This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, your ONLY task after the buzz sound will be to RECALL WORDS FROM THE TAPE. That is, the MAN-MADE (or odd-digit) task will end.

The screen will go blank once the BUZZ sound is heard. YOU SHOULD FOCUS ALL OF YOUR ATTENTION ON RECALLING AS MANY WORDS FROM THE TAPE AS YOU CAN.

Any questions? We will now begin. I will play the tape, and you should try to commit as many words to memory as you can.

*Play word list*

*After 15 seconds of counting backwards, hit spacebar to begin MAN-MADE/odd-digit task START tape-recorder at BUZZ CUE !!!!!*

Well done, now take a break so you are ready for more when we get back.

Give 5 minute break

Instructions for:

**‘odd-digit’ identification as the distracting task**

Now comes the dual-task part of the experiment. I’ll let you listen to a new set of words on the tape, then test your memory for the words.

BUT, you will have to try to recall the words from the tape while SIMULTANEOUSLY doing the odd-digit task on the computer. I’LL READ YOU AN OVERVIEW OF WHAT YOU HAVE TO DO, SO THAT YOU HAVE A GENERAL IDEA OF WHAT’S GOING TO HAPPEN.
Shortly I will play you a NEW list of 16 words that you should try your best to commit to memory. As in the practice session, you should count backwards by threes from the number at the end of the word list.

THEN, you will go to the computer and start the odd-digit test, hitting the green key whenever you notice an odd-digit is presented to you. You will continue to perform the odd-digit test ALONE, until you hear the buzzing sound.

This will be your cue to START RECALLING as many of the words from the tape that you can remember, and as before, I will be tape-recording your responses.

However, this is a dual-task experiment, so you MUST CONTINUE DOING THE odd-digit test WHILE SIMULTANEOUSLY TRYING TO RECALL WORDS FROM THE TAPE.

It is VERY important that you continue to do the odd-digit task WHILE you are trying to recall the words from the tape. **You should place a 50/50 emphasis on each task.**

Any questions?

Play study word list

After 15 seconds of counting backwards, hit spacebar to begin odd-digit task

START tape-recorder at BUZZ CUE !!!!!
REMIND Participants to keep doing odd-digit task while recalling words

Once the divided attention session is complete ask:

Now that you don’t have to do two things at the same time, can you recall any more words from the study list?

Well done, now take a break so you are ready for more when we get back.
Give 5 minute break

Instructions for:

**Baseline (single-task) “MAN-MADE (or odd-digit)” measure**

Check which distracting task they do (see order sheet)

AS was done at the beginning of the experimental phase, I now want to find out how accurate you are at the MAN-MADE (or odd-digit) task. We never collect data during practice sessions since we understand you’re just getting used to the tasks. Now I need to collect some data.
Essentially your task is the same as what you just finished doing in the practice and experimental sessions, only this time I'll collect data on your accuracy, so I can compare it with dual-task performance.

Ignore the BEEP TONE that will be heard part-way through this task.

*Hit space bar begin BASELINE repeat*

Well done.
Appendix 1.5

Instructions for auditory CRT task performed concurrently with each distracting task

You will now be doing something completely different from what you just finished doing, it involves listening to and identifying tones that you hear coming from the computer speakers.

*Read instructions from screen.*
*Point out that tones will be heard from speakers*

Your 3 fingers should always be on the keys so that you can make your response as quickly and as accurately as possible. As soon as you hit a key to identify it, the next tone will come on, and you must respond right away. As such, this is a CONTINUOUS task since you'll always be identifying a tone.

The task lasts for 2 minutes (1:55 actually) so try to stay focused.

*Start timer at SAME TIME as subject hits one of the keys to start the program.*
*Hit THEIR spacebar to end tones after 1 minute 55 seconds*

GREAT

*Set up experiment again with same subject number BUT different session number.*

Now I'll have you do the tone test all over again, but this time, after about 15 seconds of doing the tone task alone, I'll start the program for the Word-animacy / or word-2-syllable / or PICTURE animacy/ or picture SIZE/ or 2-SYLLABLE non-word/ or odd-digit id TEST.

You'll have to say 'YES' out loud whenever you see a word denoting a man-made item/ or 2-syllable word / or picture of an item that is man-made/ or PICTURE of an item that is bigger than an average computer monitor/or 2-SYLLABLE non-word/ or odd-digit is presented to you, and I will hit the green key for you over here on this keyboard.

SO, you must continue to do the tone task while simultaneously doing the distracting task on the screen. Are you clear on what you have to do??

*Start timer as soon as subject hits key to start tones.*
*After 15 seconds hit YOUR SPACEBAR to start distracting task*

*Remind subject which task they are doing distracting task*

Set up experiment again with same subject number BUT different session number.
Almost done

Now I'll have you do the tone test all over again, but this time, after about 15 seconds of doing the tone task alone, I'll start the program for the complementary distracting task from the experiment.

As before, You'll have to say 'YES' out loud whenever you see a word denoting a man-made item/ or 2-syllable word / or picture of an item that is man-made/ or PICTURE of an item that is bigger than an average computer monitor/ or 2-SYLLABLE non-word/ or odd-digit is presented to you, and I will hit the green key for you over here on this keyboard.

Start timer as soon as subject hits key to start tones.
After 15 seconds hit YOUR SPACEBAR to start distracting task

Remind subject which task they are doing
## Appendix 2.1

**Sample data collection sheet for free recall**

**Free Recall performance**

<table>
<thead>
<tr>
<th>Subject number:</th>
<th>Order of Sessions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice List</td>
<td></td>
</tr>
<tr>
<td>fountain</td>
<td>recall</td>
</tr>
<tr>
<td>landscape</td>
<td>armour</td>
</tr>
<tr>
<td>camping</td>
<td>island</td>
</tr>
<tr>
<td>nephew</td>
<td>lemon</td>
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<tr>
<td>engine</td>
<td>bookmark</td>
</tr>
<tr>
<td>cellar</td>
<td>goddess</td>
</tr>
<tr>
<td>TOTAL</td>
<td>cattle</td>
</tr>
</tbody>
</table>

| List A          |                     |
| recall  | errors | additional |
| armour   | recall  | errors | additional |
| island   | island  | recall  | errors | additional |
| lemon    | lemon   |         |        |            |
| forest   | forest  |         |        |            |
| bullet   | bullet  |         |        |            |
| artist   | artist  |         |        |            |
| organ    | organ   |         |        |            |
| vapour   | vapour  |         |        |            |
| rabbit   | rabbit  |         |        |            |
| parent   | parent  |         |        |            |
| weapon   | weapon  |         |        |            |
| elbow    | elbow   |         |        |            |
| diamond  | diamond |         |        |            |
| bookmark | bookmark |         |        |            |
| goddess  | goddess |         |        |            |
| cattle   | cattle  |         |        |            |
| TOTAL    | TOTAL   |         |        |            |

| List B          |                     |
| recall  | errors | additional |
| guitar  | recall  | errors | additional |
| needle | needle |         |        |            |
| ankle  | ankle  |         |        |            |
| party  | party  |         |        |            |
| bubble | bubble |         |        |            |
| willow | willow |         |        |            |
| lawyer | lawyer |         |        |            |
| mountain | mountain |         |        |            |
| luncheon | luncheon |         |        |            |
| robber | robber |         |        |            |
| circus | circus |         |        |            |
| olive  | olive  |         |        |            |
| ticket | ticket |         |        |            |
| village | village |         |        |            |
| pigeon | pigeon |         |        |            |
| wagon | wagon |         |        |            |
| Total  | Total   |         |        |            |

| List C          |                     |
| recall  | errors | additional |
| jury    | recall  | errors | additional |
| angel   | angel  |         |        |            |
| lecture | lecture |         |        |            |
| collar  | collar |         |        |            |
| hostage | hostage |         |        |            |
| carrot  | carrot |         |        |            |
| insect  | insect |         |        |            |
| pencil  | pencil |         |        |            |
| hotel   | hotel  |         |        |            |
| trumpet | trumpet |         |        |            |
| mansion | mansion |         |        |            |
| apple   | apple  |         |        |            |
| fabric  | fabric |         |        |            |
| arrow   | arrow  |         |        |            |
| ribbon  | ribbon |         |        |            |
| cigar   | cigar  |         |        |            |
| Total   | Total  |         |        |            |
Appendix 3.1

Sample stimuli for distracting tasks in Experiment 1

**Word-animacy task**

- canary
- hammer
- house

**Two-syllable word task**

- feather
- zebra
- camera
Appendix 3.2

Sample stimuli for distracting tasks in Experiments 2 and 3

**Picture-animacy task and Picture-size task**

![ Trumpet](image1.png) ![ Turtle](image2.png) ![ Wrench](image3.png)

**Two-syllable nonsense word task**

nario  
carpot  
lammet
Appendix 3.3

Sample stimuli for distracting tasks in Experiments 4, 5 and 6

**Word-animacy task**

- canary
- hammer
- house

**Odd-digit identification task**

- 12
- 97
- 40