Memory & Cognition
2002, 30 (5), 731-744

Factors modulating the effect of divided attention during retrieval of words

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In this study, we examined variables modulating interference effects on episodic memory under divided attention conditions during retrieval for a list of unrelated words. In Experiment 1, we found that distracting tasks that required animacy or syllable decisions to visually presented words, without a memory load, produced large interference on free recall performance. In Experiment 2, a distracting task requiring phonemic decisions about nonsense words produced a far larger interference effect than one that required semantic decisions about pictures. In Experiment 3, we replicated the effect of the nonsense-word distracting task on memory and showed that an equally resource-demanding picture-based task produced significant interference with memory retrieval, although the effect was smaller in magnitude. Taken together, the results suggest that free recall is disrupted by competition for phonological or word-form representations during retrieval and, to a lesser extent, by competition for semantic representations.

A surprising and counterintuitive finding in the memory literature is that episodic memory, for a list of unrelated words, is disrupted easily when attention is divided during encoding, but less so during retrieval. Demonstrations within a laboratory setting of a debilitating effect of divided attention (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, a familiar face, or an answer to an exam question, is an effortful task, often thwarted by distraction.

Previous studies of the effects of DA during conscious retrieval of a word list (following a single study phase) have not provided a consistent view of resource requirements. On some tests (Dywan & Jacoby, 1990; Moscovitch, 1994; Park, Smith, Dudley, & Lafronza, 1989), DA at retrieval has 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 has had little, if any, effect on memory performance (Anderson, Craik, & Naveh-Benjamin, 1998; Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Naveh-Benjamin, Craik, Guez, & Dori, 1998).

One way of understanding the diverse effects of DA at retrieval is in the context of a neuropsychological model, which ascribes different memory functions to different brain regions (Moscovitch & Umiltà, 1990, 1991). One factor that may determine the size of the interference effect of DA at retrieval is the extent to which retrieval is dependent on strategic processes mediated by the prefrontal cortex (PFC) and on associative cue-dependent processes, mediated by the medial temporal lobe/hippocampus (MTL/H) and diencephalic structures.

The model suggests that, once the necessary cues are made available, the ecphoric process (the interaction of a cue with the memory trace) is mediated by the MTL/H and is executed mandatorily and automatically. A concurrent task can interfere with memory retrieval only if, in addition to ecphory, PFC strategic processes are needed for successful retrieval (Moscovitch, 1994). The PFC is needed when the necessary retrieval cues are inadequate or unavailable, and to initiate an organized memory search, implement retrieval strategies, and monitor the output from the MTL/H to determine its veridicality and consistency with the goals of th e memory task. Thus, performing a concurrent task at retrieval will impair memory to a greater extent when the memory test requires substantial involvement of the resource-demanding PFC component. If the PFC contribution for the memory test is minimal, interference at retrieval will be small or even nonexistent (Moscovitch, 1994).

This research was supported by a scholarship from the National Sciences and Engineering Research Council of Canada (NSERC) awarded to the first author and by a grant from NSERC awarded to the second author. The authors thank Marilyne Ziegler for technical assistance and Sandra Priselac for help with data collection. Correspondence should be addressed to M. A. Fernandes, Baycrest Centre for Geriatric Care, Rotman Research Institute, 3560 Bathurst St., Toronto, ON, M6A 2E1 Canada (e-mail: mfernandes@rotman-baycrest.on.ca).

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Examples of memory tasks that are reliant on, and benefit from, frontally mediated processes include recall of categorized word lists (Moscovitch, 1994; Park et al., 1989; Stuss, Eskes, & Foster, 1994) or word lists that have organizational structure (Stuss, Craik, Sayer, Franchi, & Alexander, 1996), list discrimination (Dywan & Jacoby, 1990; Jacoby, 1991), and release from proactive inhibition (Moscovitch, 1989, 1994). Under DA conditions at retrieval, 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.

Other memory tests do not rely as heavily on strategic processes mediated by the PFC. In studies in which DA effects at retrieval were small, or even nonexistent (Anderson et al., 1998; Baddeley et al., 1984; Craik et al., 1996; 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, 1982; Schacter, 1987). As suggested by Moscovitch (1994), if the frontal lobe contribution to successful performance of the memory test is minimal, interference effects from DA at retrieval will be small, since retrieval can be performed by the modular MTL/H, which operates relatively automatically and obligatorily.

Recent work suggests, however, that, under certain conditions, a strong interference effect can be found, even on memory tests mediated primarily by the MTL/H. Fernandes and Moscovitch (2000) showed that a *word*-monitoring distracting task produced a large interference effect on memory for a list of unrelated words, whereas a similar *digit*-monitoring task did not. They proposed that retrieval can be disrupted under DA conditions at retrieval by competition for a common representational or processing system activated simultaneously during recovery of the memory trace and the word-based distracting task. In this sense, interference effects from DA at retrieval are material specific.

In this study, we tested further whether the interference effect from DA at retrieval is material or process specific. In so doing, we wished to specify the locus of interference effects at retrieval for a list of unrelated words and suggest possible underlying neural systems mediating episodic memory retrieval and the interference effect. In the first experiment, we tested whether mnemonic processing in the distracting task is crucial to produce interference with retrieval. In Experiments 2 and 3, as well as in some aspects of Experiment 1, we tested whether it was the semantic or the phonemic aspect of the distracting task that influenced the size of the interference effect on memory retrieval.

In each of our experiments, we used the same methodology and memory task as those used 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.

EXPERIMENT 1

In this experiment, we 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 have accounted for the large interference effect that they observed on memory (Craik, 2001). Recognition of words previously seen in a long list of visually presented words was one of the distracting tasks in their study (Experiment 1). Such a task requires a significant memory load, since participants have to keep several items in mind while encoding new items. It is possible that interference arose due to the memory load demands of their distracting task, rather than the verbal component as they suggested. By eliminating the memory load component of the task, we could determine whether or not it was crucial for producing the interference effect.

First, we tested whether a distracting task that involved words, but no memory load, would still produce large interference on memory performance. If material specificity is the main 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. We also considered the type of word processing required in the distracting task as a potential factor influencing the DA effect. We compared the effects of two distracting tasks: one requiring semantic processing, and the other requiring phonological processing.

In addition to the effects of DA on memory performance, previous studies have also considered performance on the distracting task itself. Craik et al. (1996), Johnston, Greenberg, Fisher, and Martin (1970), and Naveh-Benjamin and Guez (2000) have suggested that the retrieval process demands significant general processing resources, as indexed by the large decrements in distracting task performance under DA conditions with 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. In a similar vein, it has been suggested that the establishment and maintenance of retrieval mode and the monitoring of output are the resource-demanding aspects of retrieval (Craik et al., 1996; Naveh-Benjamin et al., 1998) and that costs to the distracting task are incurred regardless of similarity in material between the memory task and distracting task (Fernandes & Moscovitch, 2000). In the present experiment, we examined whether recall, which is determined more by semantic than by 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, we looked at the effect that each had on a concurrently performed auditory continuous reaction time (CRT) task. In the CRT task, the participants had to identify computer-generated tones as low-, medium-, or high-pitched tones. 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 greater resource demands.

Method

Participants

The participants were 24 undergraduate students at the University of Toronto who received either course credit or $10 for their participation.[1] All participants claimed to be native English speakers and to have normal or corrected-to-normal vision and normal hearing.

Overview of the Experiment

The 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 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, the participants continued to perform one of the distracting tasks while simultaneously trying to recall aloud the studied word list. The participants also performed a full-attention (FA) condition, in which the distracting task ended prior to free recall.

Materials

Memory task. Stimuli for the memory tasks consisted of 64 unrelated two-syllable common nouns (the same ones used as in Fernandes & Moscovitch, 2000). Words were recorded in a soundproof booth onto an audio file via a MacIntosh computer using the Sound Designer II program. We created four word lists by randomly choosing 16 words for each list from the pool of 64 words. Each word list was created with 3 sec of silence inserted between words. The lists were then recorded onto an audiotape and presented via a cassette player. All stimuli, for the memory and distracting tasks, were medium- to high-frequency words chosen from Francis and Kučera (1982), containing one, two, or three syllables, with a mean of six letters. Word frequencies ranged from 20 to 100 occurrences per million.

Distracting tasks. For the animacy task, four 50-item word lists consisting of words representing animals and man-made objects were created from a pool of 220 words. A shorter, 20-item word list was also created in the same manner and was used as the filler task for half of the participants in the FA condition prior to recall (see the Procedure section). Each list was created so that half of the words represented animals and half represented man-made objects.

For the syllable task, the same number of lists was created. These consisted of one-, two-, and three-syllable words. In each list, half of the words had two syllables, and the rest had one or three syllables. None of the words in the syllable task represented animals.

Procedure

The participants were tested individually and completed the entire experiment in approximately 1 h. For the memory task, the participants heard a tape-recorded female voice reading a list of 16 words at a rate of approximately 1 word every 4 sec and were asked to try to commit the words to memory for a later recall test. Presentation of words for the memory task was followed by an arithmetic task in which the participants counted backward by threes from a number heard at the end of each word list, for 15 sec; this was done to eliminate recency (as in Craik et al., 1996).

For the distracting tasks, words were presented visually on a computer screen at a rate of 1 word every 2 sec. For the animacy task, the participants indicated whether the word represented a man-made object, and, for the syllable task, they indicated whether it had two syllables, by pressing a key with the dominant writing hand. Although we recorded manual RTs in all of our experiments, we did not emphasize to the participants the importance of responding quickly on the distracting tasks when performed singly and in DA conditions with retrieval.

The participants were given a practice block for the memory task, followed by practice for the animacy task and then the syllable task, prior to performing all of the experimental blocks. Following the practice blocks, single-task performance for either the animacy task or the syllable task was measured. Single-task performance for the remaining distracting task was measured at the end of the final experimental condition. The order of the single tasks was counterbalanced across participants.

Following the first single-task measure, the three experimental conditions (the FA condition and two DA conditions) were administered, counterbalanced across participants. Following the study phase (and arithmetic task) in each experimental condition, and prior to recall, the participants performed either the animacy task or syllable task alone for 40 sec, until the computer emitted a low-pitched tone. The tone signaled that recall of taped words should begin. For the DA conditions, this was done so that the participants would be engaged in the distracting task prior to beginning recall. In the FA condition, this filler task (the 20-item word list) ended once the computer signaled that recall of the taped words should begin. In this way, the time lag between when the words for the recall task were studied, and the need to perform another task before recall, were the same in the DA and FA conditions.

In the two DA conditions, the animacy task or the syllable task continued on the computer while the participants simultaneously tried to recall studied words. The distracting and free recall tasks were performed simultaneously for 60 sec, and the 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 the participants whether they recalled any additional words from the study list, now that they did not have to do two things simultaneously. For all orders of experimental conditions, the participants were given a 4-min break before beginning the next condition. The participants' recall responses were tape-recorded.

Comparing resource demands of the distracting tasks. We used the auditory CRT task to compare the resource demands of the animacy and syllable distracting tasks and took this as a measure of each task's level of difficulty. For the CRT task, the participants had to identify computer-generated tones as low, medium, or high in pitch. The tones were played in a random order, and the 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 sec had elapsed.

Each participant performed the CRT task in three different conditions, for 115 sec each: alone for a baseline measure, and under DA conditions with the animacy and syllable tasks. For the DA conditions, in order to avoid having the participants make different manual responses for the CRT and distracting tasks, we asked the participants to make verbal responses in identifying words (man-made words for the animacy task and two-syllable words for the syllable task). The experimenter recorded the participants' re-

Table 1
Number of Words Recalled and Mean Percentage Decline in Words Recalled from Full-Attention (FA) to Divided-Attention (DA) Conditions in Each Experiment

Condition	Words Recalled *M*	Words Recalled *SD*	Percentage Decline *M*	Percentage Decline *SD*
	Experiment 1			
FA	7.46	2.38		
DA animacy	4.79	2.15	35.33	23.00
DA syllable	5.29	2.35	28.43	23.48
	Experiment 2			
FA	7.54	2.23		
DA picture animacy	6.08	1.93	16.00	24.60
DA nonsense word	5.08	2.06	30.68	26.03
	Experiment 3			
FA	8.77	2.45		
DA picture size	7.25	2.88	16.60	28.37
DA nonsense word	6.54	2.99	25.29	27.56

sponses by pressing a key on a separate keyboard. The RTs and the number of correct responses in the auditory CRT were recorded and analyzed as a means of gauging how demanding each distracting task was, with longer RTs indicating greater resource demands.

Results

Memory task

The animacy and syllable distracting tasks interfered substantially with free recall performance, and there was no difference in the magnitude of this effect across DA conditions. The means for each condition are presented in Table 1. There was no difference in the number of words recalled in the FA condition depending on the type of filler task used prior to recall [$t(22) = -0.59, p > .05$]. The data were analyzed in a 6 × 2 × 3 analysis of variance (ANOVA), with order of experimental condition and order of single-task measure for the animacy task and the syllable task as between-participants factors and with experimental condition as a within-participants factor. 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 [$F(2,46) = 21.70$, $MS_e = 2.22$]. The mean number of words recalled in both the animacy DA condition and the syllable DA condition was reduced significantly from the mean in the FA condition [$F(1,23) = 56.62$, $MS_e = 3.01$, and $F(1,23) = 31.10$, $MS_e = 3.62$, respectively]. The difference in number of words recalled in the animacy DA condition and the syllable DA condition was not significant [$F(1,23) = 0.90$, $MS_e = 6.70$]. The percentage decline in words recalled from FA to DA conditions did not differ for the two DA conditions.

Following each DA condition, the participants were given the chance to recall any additional words from the study list. The mean numbers of additional words recalled following the animacy and syllable DA conditions were only 0.54 (*SD* = 0.83) and 0.54 (*SD* = 0.93), respectively.

Distracting tasks

Accuracy rate. Accuracy rates (calculated as hit rate minus false alarm rate) on the animacy task and the syllable task in the DA conditions were worse than single-task performance. The percentage decline in accuracy rate, from single-task to dual-task conditions, was larger on the syllable task than on the animacy task, but the difference was not significant. There were no significant main effects or interactions with the order factors on distracting task performance. The data were analyzed in a 2 × 2 ANOVA, with attention (full vs. divided attention) and task (animacy vs. syllable) as within-participants factors. The mean accuracy rates for each task, in each condition, are presented in Table 2. There was a main effect of attention [$F(1,23) = 43.61$, $MS_e = 0.02$] and a main effect of task [$F(1,23) = 4.30$, $MS_e = 0.02$]. The attention × task interaction, however, was not significant [$F(1,23) = 1.60, p > .05$].

The correlation between accuracy rate on each distracting task in the DA conditions and memory interference for that condition was nonsignificant. This correlation was calculated in all experiments and was always nonsignificant.

Reaction time. The mean RTs in each distracting task in the single-task and DA conditions with retrieval are noted in Table 2. The data were analyzed in a 2 × 2 ANOVA, with attention (full vs. divided attention) and task (animacy vs. syllable) as within-participants factors. There was a main effect of attention [$F(1,23) = 21.29$, $MS_e = 13{,}591.64$] and a main effect of task [$F(1,23) = 16.89$, $MS_e = 27{,}540.36$]. The attention × task interaction was also significant [$F(1,23) = 9.01$, $MS_e = 15{,}954.04$]. The baseline RT was significantly longer for the syllable task than for the animacy task [$t(22) = -5.49$]. The percentage increase in RT from baseline to dual-task conditions was significantly greater for the animacy task than for the syllable task [$t(23) = 2.99, p < .05$].

The correlation between RT on each distracting task in the DA conditions and memory interference for that condition was nonsignificant. This correlation was calculated in all experiments and was always nonsignificant.

Auditory CRT

Distracting task. The accuracy rate (calculated as hit rate minus false alarm 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 task and the syllable task, performed concurrently with the CRT tone task, were .44 (*SD* = .23) and .46 (*SD* = .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 numbers of correct responses for each condition are presented in Table 3. A within-participants ANOVA revealed a main effect of

Table 2
Accuracy Rate and Reaction Time (RT, in Milliseconds) on Distracting Tasks and Percentage Change from Single Task to Divided Attention for Each Measure and Condition in Each Experiment

Condition	Accuracy Rate		% Decline in Accuracy Rate		RT		% Increase in RT	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Experiment 1								
Baseline animacy	.79	.08			842.88	104.99		
DA animacy	.61	.13	22.19	18.30	1,030.08	144.21	16.94	13.60
Baseline syllable	.75	.11			1,059.50	188.74		
DA syllable	.51	.24	32.51	30.19	1,091.92	174.09	1.74	19.12
Experiment 2								
Baseline picture animacy	.95	.14			653.42	112.35		
DA picture animacy	.85	.14	6.21	32.12	817.00	160.51	18.45	14.61
Baseline nonsense word	.83	.17			1,073.54	195.64		
DA nonsense word	.57	.18	31.74	17.40	1,062.29	198.68	−0.02	17.02
Experiment 3								
Baseline picture size	.91	.06			685.31	80.11		
DA picture size	.73	.13	19.84	14.59	787.25	92.36	12.42	9.20
Baseline nonsense word	.89	.12			982.00	186.26		
DA nonsense word	.65	.19	26.28	20.39	1,041.27	191.71	4.73	14.90

Note—Accuracy rate = hits − false alarms; DA, divided attention.

condition [$F(2,40) = 82.17$, $MS_e = 82.08$]. There were no main effects or interactions with the order factor. Planned comparisons showed that the number of tones correctly identified in both the animacy DA condition and the syllable DA condition differed significantly from the FA baseline condition [$F(1,20) = 169.17$, $MS_e = 102.69$, and $F(1,20) = 100.26$, $MS_e = 226.79$, respectively]. The number of tones identified in the animacy and syllable DA conditions was not significantly different.

The mean RTs to identify tones are shown for correct responses only (see Table 3). An outlier analysis eliminated RTs greater or lesser than 2 standard deviations from the mean for each participant in each condition. A within-participants ANOVA revealed a main effect of condition [$F(2,40) = 28.64$, $MS_e = 9{,}537.11$]. There were no significant main effects or interactions with the order factor. The mean RTs in both the animacy DA condition and the syllable DA condition differed significantly from the mean in the baseline condition [$F(1,20) = 58.31$, $MS_e = 12{,}819.02$, and $F(1,20) = 34.77$, $MS_e = 25{,}466.43$, respectively]. The difference in RT between the animacy and syllable DA conditions was not significant [$F(1,20) = 0.31$], suggesting that the two distracting tasks made 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. Our results suggest that recall of words 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 the component-process 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, we conclude that competition might occur at a presemantic level, perhaps for phonemic or word-form representations. This hypothesis was evaluated further in Experiments 2 and 3.

We found that performance on the animacy and syllable distracting tasks was significantly affected in the DA

Table 3
Number of Correct Responses and Reaction Time (in Milliseconds) on the Auditory Continuous Reaction Time Task for Each Condition in Each Experiment

Condition	Correct Responses		Reaction Time	
	M	*SD*	*M*	*SD*
Experiment 1				
Baseline	102.91	20.00	735.04	165.83
DA animacy	74.14	16.60	923.71	234.08
DA syllable	70.00	19.71	940.37	264.91
Experiment 2				
Baseline	91.58	19.45	840.26	187.67
DA picture animacy	64.38	17.91	961.54	168.69
DA nonsense word	61.96	16.35	1,046.34	217.99
Experiment 3				
Baseline	98.37	25.97	706.73	180.69
DA picture size	84.37	24.45	892.91	233.28
DA nonsense word	84.37	25.56	913.69	233.35

Note—DA, divided attention.

conditions. The magnitude of interference on accuracy rate was consistent with that obtained in studies that used nonverbal distracting tasks, even though we observed larger effects on memory performance. As originally suggested by Craik et al. (1996), Johnston et al. (1970), and Naveh-Benjamin and Guez (2000), 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. As such, it does not operate automatically, as Baddeley et al. (1984) claimed.

A direct analysis of resource demands using the auditory CRT task showed that the animacy and syllable distracting tasks had similar effects on the number of tones identified and on RT in the auditory CRT task. Moreover, the accuracy rates in the DA conditions with the auditory CRT task were similar. This suggests that the two distracting tasks were equally resource demanding and, by our interpretation, equally difficult. It should be noted that accuracy rate on the syllable distracting task, performed alone and under the DA condition with retrieval, was poorer than on the animacy task. We acknowledge that this measure indicates that there are some inherent differences with respect to difficulty between the tasks. However, the task × attention interaction was not significant, indicating that this difference did not lead to increased costs under the DA conditions. Moreover, accuracy rate on each task under DA conditions was unrelated to memory interference.[2]

Because the resource demands of the distracting tasks were equivalent (according to the auditory CRT analysis), a possible interpretation of our finding is that retrieval interference depends on this factor alone. We do not endorse this view and instead favor a material-specific account over a resource-competition account of retrieval interference. Our previous work comparing the effects of digit and word monitoring distracting tasks (Fernandes & Moscovitch, 2000) showed that, even though these monitoring tasks 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 was explored further in the subsequent experiments.

EXPERIMENT 2

The common factor across all experiments in which large interference effects from DA at retrieval were found (in Fernandes & Moscovitch, 2000, as well in Experiment 1 of the present study) is that the distracting task involved verbal material. In this experiment, we investigated what aspect of the words in the distracting task had the greatest influence on the size of the interference effect, either the semantic or the word-form component.

To address this question, we compared the interference effect on memory produced from two different DA conditions at retrieval, one in which the distracting task retained a semantic component but had no word-form component, and another in which there was a word-form component, but no semantic component. One of the distracting tasks required the participants to identify line drawings representing man-made objects among line drawings of animals and man-made items, whereas the other distracting task required them to identify two-syllable nonsense words among one-, two-, and three-syllable pronounceable nonsense words.

Recall that the results of Experiment 1 showed the level of processing required in the distracting task did not influence the size of the interference effect. This led us to suggest that competition at a presemantic word-form level was responsible for the large interference effects on memory. If competition under DA at retrieval occurs at a presemantic level, a distracting task that involves word-like material or phonological processing, without semantics, should still impair the retrieval process. Along the same lines, a distracting task that consists of picture material and requires semantic processing without a word-form component should produce much less interference with retrieval.

As in Experiment 1, we also considered changes in accuracy rate on each distracting task performed alone and concurrently with retrieval. We expected significant declines in performance under DA conditions, since retrieval is a resource-demanding process (Craik et al., 1996; Fernandes & Moscovitch, 2000; Johnston et al., 1970). Furthermore, because the nonsense-word and picture tasks involved different materials, we also tested the claim that distracting task costs are incurred under DA conditions with retrieval, regardless of the material used in the distracting task (Fernandes & Moscovitch, 2000).

Because we were examining whether the picture-animacy and nonsense-word distracting tasks would produce similar amounts of interference on memory, we wanted to ensure that any differences were not due to differential resource demands. To this end, we assessed resource demands by comparing performance on each distracting task performed concurrently with the auditory CRT task.

Method

Participants

The participants were 24 naive undergraduate students at the University of Toronto who received $10 for their participation.[3] All participants claimed to be native English speakers and to have normal or corrected-to-normal vision and normal hearing.

Overview of the Experiment

Experiment 2 was identical to Experiment 1, except that the word-based animacy and syllable distracting tasks were replaced by the picture-animacy and nonsense-word tasks.

Materials

Memory task. Stimuli for the memory tasks were identical to those in Experiment 1.

Distracting tasks. Stimuli for the picture-animacy task consisted of 220 black line drawings (from Snodgrass & Vanderwart, 1980, as well as pictures drawn by a colleague, which were easily identifiable to participants in a pilot study) presented on a white background. Each picture was 170 × 170 pixels in size. Four 50-item picture lists and one 20-item picture list were created such that half of the pictures represented man-made objects and the other half represented animals.

The stimuli for the nonsense-word task consisted of 220 pronounceable nonsense words, which we created by changing one to three letters of words used in the syllable distracting task or the animacy distracting task described in Experiment 1. Letters were changed such that the newly created nonsense word was pronounceable. A research assistant and the first author 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 in each list had two syllables, and the rest had one or three syllables.

Procedure

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. For the picture-animacy task, the participants indicated whether the presented picture represented a man-made object by making a keypress with the dominant writing hand. For the nonsense-word syllable task, the participants indicated whether the presented nonsense word had two syllables by making a keypress. We also considered each participant's performance on the auditory CRT task, performed alone and under DA conditions, with that on each of the distracting tasks.

Results

Memory Task

The nonsense-word syllable task interfered substantially with memory 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 1. There was a significant difference in the number of words recalled in the FA condition, depending on the type of filler task used prior to recall [$t(22) = 2.29, p > .05$]. The participants performing the nonsense-word task as the filler recalled fewer words ($M = 6.6$, $SD = 2.12$) than those who performed the picture-animacy task as the filler ($M = 8.5$, $SD = 1.98$). The data were analyzed in a 6 × 2 × 3 ANOVA, with order of experimental condition and order of single-task measure for the picture-animacy and nonsense-word tasks as between-participants factors and with experimental condition as a within-participants factor. 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 [$F(2,46) = 18.89, MS_e = 1.94$]. For both DA conditions, the number of words recalled was significantly lower than that for the FA condition [$F(1,23) = 11.74, MS_e = 4.35, p < .01$, and $F(1,23) = 30.9, MS_e = 4.69$, for the picture-animacy and nonsense-word conditions, respectively]. The mean number of words recalled in the picture-animacy DA condition differed significantly from the mean in the nonsense-word DA condition [$F(1,23) = 9.20, MS_e = 2.61, p < .01$]. The difference in percentage decline in memory (from FA to DA conditions) for the picture-animacy and nonsense-word DA conditions was significant [$t(23) = -2.89, p < .01$].

Following each DA condition, the participants were given the chance to recall any additional words from the study list. The participants recalled an additional 0.42 ($SD = 0.65$) and 0.67 ($SD = 1.09$) words following the picture-animacy and nonsense-words DA conditions, respectively. The difference between conditions was not significant.

Distracting Tasks

Accuracy rate. Accuracy rates on the nonsense-word and picture-animacy tasks under DA conditions were worse than in single-task performance. The percentage decline in accuracy rate from single to DA conditions was significantly larger on the nonsense-word task than on the picture-animacy task [$t(23) = -3.02, p < .01$]. There were no significant main effects or interactions with the order factors on distracting task performance.

The data were analyzed in a 2 × 2 ANOVA, with attention (full vs. divided attention) and task (picture animacy vs. nonsense word) as within-participants factors. The mean accuracy rates for each task in each condition are presented in Table 2.

There was a main effect of attention [$F(1,23) = 78.50, MS_e = 0.01$] and a main effect of task [$F(1,23) = 46.63, MS_e = 0.02$]. The attention × task interaction was also significant [$F(1,23) = 9.83, MS_e = 0.02, p < .01$].

Reaction time. The mean RT for each distracting task in the single-task and DA conditions with retrieval is noted in Table 2. The baseline RT was significantly longer for the nonsense-word task than for the picture-animacy task [$t(23) = -11.47$]. The percentage increase in RT from baseline to dual-task conditions was significantly greater for the picture-animacy task than for the nonsense-word task [$t(23) = 4.34$].

The data were analyzed in a 2 × 2 ANOVA, with attention (full vs. divided attention) and task (picture animacy vs. nonsense word) as within-participants factors. There was a main effect of attention [$F(1,23) = 12.68, MS_e = 10{,}977.16$] and a main effect of task [$F(1,23) = 115.24, MS_e = 23{,}052.93$]. The attention × task interaction was also significant [$F(1,23) = 12.84, MS_e = 14{,}278.44$].

Auditory CRT

Distracting task. Accuracy rates on the picture-animacy and nonsense-word tasks were .67 ($SD = .16$) and .48 ($SD = .18$), respectively, when each was performed concurrently with the auditory CRT task; this difference in performance was significant [$t(23) = 4.42$]. There was no effect of task order.

CRT tone task. The difference in the number of tones correctly identified in the picture-animacy and nonsense-word DA conditions was not significant. The mean number of correct responses for each condition is presented in Table 3. A within-participants ANOVA showed a main effect of condition [$F(2,46) = 107.95, MS_e = 60.17$]. There were no main effects or interactions with the order factor. Planned comparisons showed that the number of tones correctly identified in the picture-animacy and nonsense-word DA conditions differed significantly from that in the FA baseline condition [$F(1,23) = 116.42, MS_e = 152.61$, and $F(1,23) = 129.27, MS_e = 162.94$, respectively].

The mean RT to identify tones is shown for correct responses only (see Table 3). A within-participants ANOVA revealed a main effect of condition [$F(2,46) = 18.58$, $MS_e = 13{,}855.26$]. There were no significant main effects or interactions with the order factor. The mean RT in the picture-animacy and nonsense-word DA conditions differed significantly from the mean RT in the baseline condition [$F(1,23) = 16.20, MS_e = 21{,}787.87, p < .01$, and $F(1,23) = 21.00, MS_e = 48{,}523.42$, respectively]. The difference in RT between the two DA conditions was significant [$F(1,23) = 13.46, MS_e = 12{,}820.27, p < .01$].

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 distracting task. The picture-animacy task produced a smaller effect on memory, although it was still significant. These results are consistent with the suggestion from Experiment 1 that the primary locus of interference under DA at retrieval occurs at a presemantic 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 on recall occur primarily due to competition for a word-based representational system (Fernandes & Moscovitch, 2000), although they do not exclude other sources of interference.

It should be noted that single-task performance of the nonsense-word task and the percentage decline in accuracy rate from single to DA conditions is comparable to those 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 DA conditions was similar in the nonsense-word DA condition to that in the DA conditions 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 an interference effect on memory, it was nonetheless significant. 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, although to a lesser degree. Another possible interpretation is that the pictures might on occasion activate the word-form or phonological representation. Because this did not occur on all trials, the interference effect was diminished.

It should also be noted that the picture-animacy task was shown on multiple measures to be easier to perform than was the nonsense-word task. There was a smaller decrement in accuracy rate from single to DA conditions, and, when performed concurrently with the auditory CRT task, the accuracy rate on the picture-animacy task was higher and the RT on the tone task was faster than in the nonsense-word DA condition. 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 the results of Experiment 2 would suggest. We explored this possibility in Experiment 3.

Alternatively, one might suggest that the large interference effect on memory from the nonsense-word distracting task was due to retroactive interference when this task was performed in the 40 sec prior to free recall (Underwood, 1957). A between-participants comparison of performance in the FA condition showed worse recall performance when the nonsense-word task, relative to the picture-animacy task, was the filler performed prior to recall. However, this difference could simply reflect differences in task difficulty. This possibility was examined in Experiment 3.

Examination of distracting task costs shows the expected decline in accuracy rate from single to DA conditions for both the picture-animacy task and the nonsense-word task. Thus, as previous work suggests, 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 in the distracting tasks from Experiment 1. The decrement on the picture-animacy task is smaller. Fernandes and Moscovitch (2000) suggest 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 the picture-animacy task was less resource demanding than was the nonsense-word task. This could account for the smaller decrement in the distracting task performance under DA conditions with retrieval.

EXPERIMENT 3

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 us 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, although the results of Experiment 2 did not allow us to determine the extent. The purpose of

Experiment 3 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 with respect to resource demands. In Experiment 3, we created a new picture-based distracting task that required the 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 judgment task was more resource demanding than was the picture-animacy task.

In this experiment, we 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 should the nonsense-word syllable task. As in Experiments 1 and 2, the auditory CRT task was used to compare resource demands of the distracting tasks.

Experiment 3 also allowed us to reexamine 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 tasks than on competition for material-specific representational systems.

Method

Participants

The participants were 48 naive undergraduate students at the University of Toronto who received $10 for their participation.[4] All participants claimed to be native English speakers and to have normal or corrected-to-normal vision and normal hearing.

Overview of the 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

Memory task. Stimuli for the memory tasks were identical to those in Experiments 1 and 2.

Distracting tasks. Stimuli for the picture-size task consisted of 220 black line drawings (from Snodgrass & Vanderwart, 1980, as well as pictures drawn by a colleague, which were easily identifiable to participants in a pilot study) presented on a white background. Each picture was 170 $\times$ 170 pixels. Four 50-item picture lists and one 20-item picture list were created. Half of the pictures in each list represented objects that in the real world were bigger than a computer monitor, and the other half represented objects smaller than a monitor. The participants indicated whether the presented picture was one of the former type.

The materials used for the nonsense-word task were the same as those used in Experiment 2.

Procedure

The procedure was identical to that described in Experiments 1 and 2, except that the animacy and syllable tasks were replaced by the picture-size and nonsense-word distracting tasks.

Results

Memory Task

Again, the nonsense-word syllable task interfered substantially with free recall performance; interference was not as great when the picture-size task was performed concurrently at retrieval. There was no difference in the number of words recalled in the FA condition depending on the type of filler task used prior to recall [$t(46) = -0.88$, $p > .05$]. The data were analyzed in 6 $\times$ 2 $\times$ 3 ANOVA, with order of experimental condition and order of single-task measure for the picture-size and nonsense-word tasks as between-participants factors and with experimental condition as a within-participants factor. 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 [$F(2,94) = 20.60$, $MS_e = 3.02$]. For both DA conditions, the number of words recalled was significantly lower than that in the FA condition [$F(1,47) = 18.37$, $MS_e = 6.04$, and $F(1,47) = 39.69$, $MS_e = 6.01$, for the picture-size and nonsense-word conditions, respectively]. The difference in number of words recalled in each DA condition was significant [$F(1,47) = 3.96$, $MS_e = 6.08$, $p = .05$]. The difference in percentage decline in memory (from FA to DA conditions) between the picture-size and nonsense-word DA conditions was also significant [$t(47) = -2.05$, $p < .05$].

Following each DA condition, the participants were given the chance to recall any additional words from the study list. The number of additional words recalled after the picture-size and nonsense-word syllable DA conditions was 0.875 ($SD = 0.95$) and 1.12 ($SD = 1.36$), respectively. The difference between conditions was not significant.

Distracting Tasks

Accuracy rate. Accuracy rates on the nonsense-word and picture-size tasks under DA conditions with free recall were worse than in single-task performance. The percentage decline in accuracy rate from single-task to dual-task conditions was larger on the nonsense-word task than on the picture-size task, but the difference was not significant [$t(47) = -1.86$, $p > .05$]. There were no significant main effects or interactions with the order factors on distracting task performance.

The data were analyzed in a 2 $\times$ 2 ANOVA, with attention (full vs. divided attention) and task (picture size vs. nonsense word) as within-participants factors. The mean accuracy rates for each task in each condition are presented in Table 2. There was a main effect of attention [$F(1,47) = 153.63$, $MS_e = 0.01$] and a main effect of task [$F(1,47) = 4.69$, $MS_e = 0.02$, $p < .05$]. The attention $\times$ task interaction, however, was not significant [$F(1,47) = 3.19$, $MS_e = 0.01$, $p > .05$].

Reaction time. The mean RT for each distracting task in the single-task and DA conditions with retrieval is noted in Table 2. The baseline RT was significantly longer for the nonsense-word task than for the picture-size task [$t(47) = -10.61$]. The percentage increase in RT from baseline to dual-task conditions was significantly greater for the picture-size task than for the nonsense-word task [$t(47) = 2.88, p < .01$].

The data were analyzed in a 2 × 2 ANOVA, with attention (full vs. divided attention) and task (picture size vs. nonsense word) as within-participants factors. There was a main effect of attention [$F(1,47) = 43.68$, MS_e = 7,139.39] and a main effect of task [$F(1,47) = 137.55$, MS_e = 26,459.06]. The attention × task interaction, however, was not significant [$F(1,47) = 2.48$, MS_e = 8,799.44].

Auditory CRT [5]

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 .59 (*SD* = .16) and .54 (*SD* = .25), respectively. There was no effect of task order on accuracy rate for the picture-size or nonsense-word task.

CRT tone task. The difference in the number of tones correctly identified when the CRT task was performed concurrently with the picture-size task, relative to when it was performed with the nonsense-word task, was not significant. The mean number of correct responses for each condition is presented in Table 3. A within-participants ANOVA revealed a main effect of condition [$F(2,90)$ = 17.80, MS_e = 168.83]. There were no main effects or interactions with the order factor. Planned comparisons showed that the number of tones correctly identified in the picture-size and nonsense-word DA conditions differed significantly from that in the baseline condition [$F(1,45)$ = 21.56, MS_e = 418.27, and $F(1,45)$ = 19.46, MS_e = 463.33, respectively].

The mean RT to identify tones is shown for correct responses only (see Table 3). An outlier analysis eliminated RTs greater or lesser than 2 standard deviations from the mean for each participant in each condition. A within-participants ANOVA revealed a main effect of condition [$F(2,90)$ = 63.26, MS_e = 9,444.73]. There were no significant main effects or interactions with the order factor. The mean RT in the picture-size and nonsense-word DA conditions differed significantly from the mean in the baseline condition [$F(1,45)$ = 82.85, MS_e = 19,244.88, and $F(1,45)$ = 95.45, MS_e = 20,642.84, respectively]. The difference in RT between the two DA conditions was not significantly different [$F(1,45) = 1.18, p > .05$].

Discussion

The nonsense-word distracting task performed concurrently with free recall produced a 25% decline in memory compared with the FA condition, whereas the picture-size task produced a 17% decline. These both represent significant interference with free recall, although the effect was larger in the case of the nonsense-word distracting task. In contrast, the interference on accuracy rate for each distracting task, under DA conditions, did not differ significantly: A 20% decline and a 26% decline in distracting task performance were observed in the DA picture-size and DA nonsense-word conditions, respectively.

The 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 DA condition and the RT in the auditory CRT task did not differ significantly between them. Moreover, the accuracy rates in DA conditions with the auditory CRT task were similar for the picture-size and nonsense-word tasks. Thus, differences with respect to resource demands for each task did not underlie the pattern of memory interference from each DA condition.

Although single-task RT for each distracting task differed, we do not believe that this accounts for the difference in their effects on memory. In Experiment 1, the single-task 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 distracting task RT are not related to the amount of interference produced on memory under DA conditions. In agreement with this, we found no correlation between RT for each distracting task with memory interference in any of our experiments.

In Experiment 3, there was no indication that memory interference could have been due to retroactive interference from the nonsense-word task performed prior to recall. Unlike in Experiment 2, recall did not differ depending on whether the nonsense-word task or the picture-size task was the filler performed prior to recall in the FA condition. Thus, an explanation of the large memory interference effect from the nonsense-word DA condition, in terms of disruption of consolidation or storage by the distracting task performed prior to recall, is unlikely.

Overall, the nonsense-word distracting task produced large interference effects on memory, similar in magnitude to those observed in Experiments 1 and 2 and to those observed from verbal-based distracting tasks in Fernandes and Moscovitch (2000). Thus, processing word forms, without semantic content, can significantly disrupt the retrieval process. An equally resource-demanding picture-based distracting task produces significant, though smaller, effects on memory, indicating that competition for semantic representations plays a lesser role in modulating interference from DA at retrieval.

GENERAL DISCUSSION

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), in which a verbal running recognition task and a word monitoring distracting task led to an approximate 30% decline in memory performance from FA to DA con-

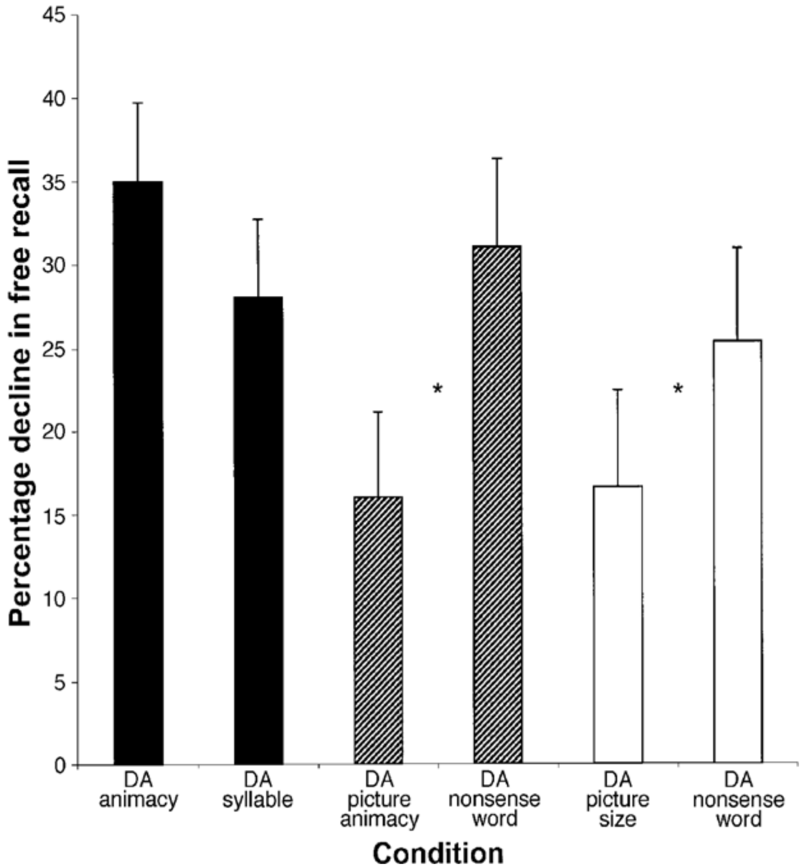

Figure 1. Mean percentage decline in free recall performance from full to divided attention (DA) for each condition in Experiments 1 (solid bars), 2 (diagonal bars), and 3 (open bars). *Significant difference between conditions.

ditions at retrieval. These results stand in contrast to the results of other studies of verbal memory in which retrieval was performed concurrently with nonverbal distracting tasks, such as card sorting tasks (Baddeley et al., 1984), digit monitoring tasks (Fernandes & Moscovitch, 2000), or visuospatial tasks (Anderson et al., 1998; Craik et al., 1996; Naveh-Benjamin et al., 1998), which led to small interference effects on memory.

Our study was designed to investigate what aspect of verbal-based distracting tasks leads to large interference effects on memory and, in so doing, to provide insight into the resources and underlying neural systems necessary for retrieval. Competition for word-form or phonological representations is sufficient to produce large interference effects on free recall on its own. An equally resource-demanding picture-based distracting task produced significant interference with memory retrieval, but the effect was significantly smaller in magnitude (see Figure 1).

Although smaller, the declines in memory from the picture tasks suggest that competition for semantic representations or for general resources can also disrupt the retrieval process. 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. Thus, nonverbal 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. It is likely that some amount of attention is required for memory retrieval and is compromised by having to coordinate another task along with it, leading to small yet significant interference effects. Alternatively, because the pictures were line drawings of common objects, the participants may have accessed the name on some trials, which led to interference effects at a phonological level.

Although we considered only verbal memory, results from another group found similar material-specific effects of DA at retrieval. Robbins et al. (1996) found that memory for the arrangement of chess pieces was affected more by a visuospatial distracting task than by a verbal-articulatory distracting task.

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

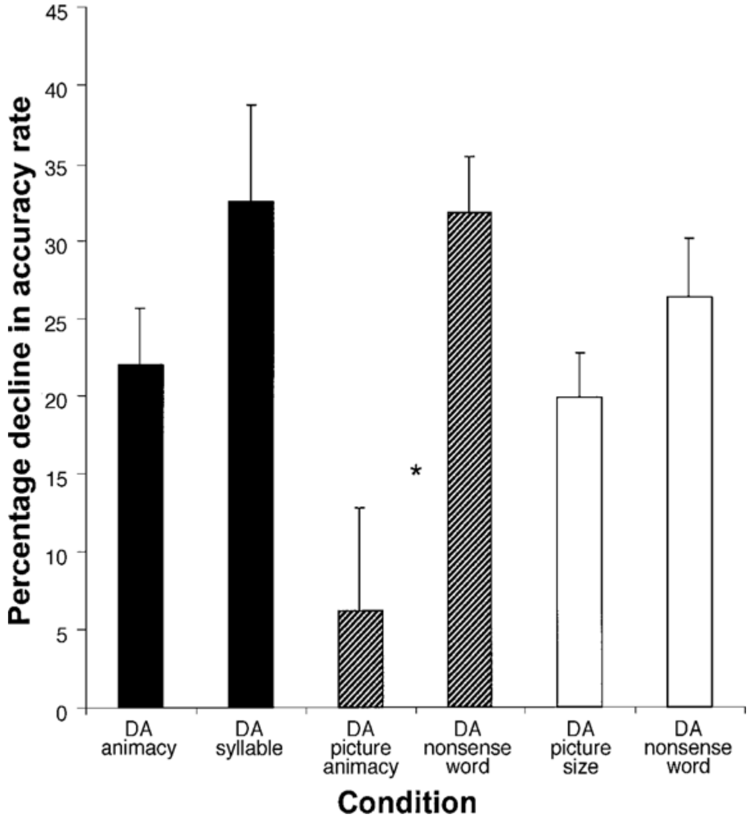

Figure 2. Mean percentage decline in accuracy rate from single to divided attention (DA) for each condition in Experiments1 (solid bars), 2 (diagonal bars), and 3 (open bars). *Significant difference between conditions.

Craik et al. (1996), Anderson et al. (1998), and Naveh-Benjamin et al. (1998), retrieval is not an automatic process, since it draws away resources from the distracting task under DA. Although the size of interference on distracting tasks across experiments fluctuated, material specificity was not the factor producing this variability.[6] In Experiment 3, interference effects on accuracy for the picture-size task did not differ from those for the nonsense-word task, despite the fact that different materials were used (see Figure 2).

A Model of Retrieval

What do these findings tell us about how retrieval operates? As suggested in the component-process model, successful retrieval requires establishing and maintaining retrieval mode and/or monitoring output, mediated by the PFC and ecphory, which consists of reactivation of the memory trace by its interaction with memory cues. The first component is resource demanding and, under DA conditions, is believed to be reflected in costs to the distracting task. Because the memory task used in this study was free recall, these costs may also have been due to initiation of search or monitoring outcome. Our design did not permit us to determine which of these processes accounts for distracting task costs, though it did allow us to conclude that retrieval requires some amount of general resources and that material specificity does not modulate these costs.

The second component in the model is ecphory. We believe that performing a task that requires processing of words or word-like material concurrently with recall of words can disrupt the neocortical representations that constitute the memory, leading to large interference effects. By this account, DA at retrieval using an implicit test of memory should also result in a material-specific interference effect. We will be considering this prediction in future work.

An alternative account of these results is that interference from word-based distracting tasks occurs due to competition for working memory (WM) space during input and output. That is, processing of incoming words for the distracting task may occur in WM. At the same time, words for the recall task may also need to be held in WM before responding, leading to competition. If we consider WM (phonological buffer and articulatory loop) in the way described by Baddeley and Hitch (1974), only verbal-based distracting tasks should interfere with recall, whereas spatial-based distracting tasks can be carried out using the visuospatial scratchpad, thereby eliminating any competition for WM resources. Furthermore, according to this account, one would expect interference to occur only when the distracting task requires phonological processing, since this is the code used by this slave system to process verbal material.

This alternative account suggests that words to be recalled are successfully reactivated but then disrupted at output. The component-process model, on the other hand, suggests that interference occurs during reactivation of the memory traces, prior to output. We favor the latter interpretation, since it accounts for the observed persistent effects of DA, when words or word forms are in the distracting task; once disrupted, the memories are rarely recovered, even when the DA condition ends. Our experiments, however, did not allow one to distinguish which account is correct.

Importantly, our experiments established that retrieval is not an obligatory process, as others have suggested (Anderson et al., 1998; Craik et al., 1996; Naveh-Benjamin et al., 1998), and they specify a sufficient condition for large interference effects from DA at retrieval. Phonological processing of orthographic material in a distracting task interferes with retrieval of words. Although semantic processing in the distracting task also interferes with retrieval, it does so to a lesser degree. These findings must be taken into account if we wish to understand and model the processes and neural systems involved during retrieval of verbal material.

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NOTES

1. Data from 1 participant were excluded because of a misunderstanding of 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, data for 3 participants were invalid and/or lost.

2. There were also differences with respect to RT for each distracting task, with syllable decisions taking longer to perform. This could be interpreted as an indication of differential resource demands for each task (contrary to the conclusions based on the auditory CRT analysis). We acknowledge that resource demands as measured by the auditory CRT task may be different than difficulty as measured by speed and accuracy

measures on the distracting tasks under the experimental conditions. We see no easy way to account for this discrepancy. Because we did not emphasize in our instructions the need to respond quickly, it is difficult to draw conclusions from speed–accuracy data.

3. It was decided, preexperimentally, to exclude the participants who recalled five words or less under FA conditions. This resulted in the exclusion of data from 3 participants. Data from 1 participant were excluded because of a misunderstanding of the task instructions. Additional participants were tested in their place.

4. Data from several participants were excluded from Experiment 3 because they did not perform at a preexperimentally determined level of performance on one of the tasks under DA conditions: Three participants had accuracy rates of zero or near zero on the nonsense-word task under DA conditions. Seven participants were excluded because the number of words they recalled in the FA condition was five words or less, and 2 participants claimed their memory went blank in the experimental conditions. Additional participants were tested in their place.

5. Due to experimenter error, data on auditory CRT performance for 2 participants were invalid and/or lost. Data from only 46 participants are included.

6. We 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 were the other tasks in this study (see Experiment 2, Results and Discussion section).

(Manuscript received April 16, 2001;
revision accepted for publication January 9, 2002.)