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Divided Attention and Memory: Evidence of Substantial Interference Effects at Retrieval and Encoding

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In 5 divided attention (DA) experiments, students (24 in each experiment) performed visual distracting tasks (e.g., recognition of words, word and digit monitoring) while either simultaneously encoding an auditory word list or engaging in oral free recall of the target word list. DA during retrieval, using either of the word-based distracting tasks, produced relatively larger interference effects than the digit-monitoring task. DA during encoding produced uniformly large interference effects, regardless of the type of distracting task. Results suggest that when attention is divided at retrieval, interference is created only when the memory and concurrent task compete for access to word-specific representational systems; no such specificity is necessary to create interference at encoding. During encoding, memory and concurrent tasks compete primarily for general resources, whereas during retrieval, they compete primarily for representational systems.

The main purpose of our studies was to investigate the effects of divided attention (DA), during either encoding or retrieval, on long-term memory (LTM). 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.

Past studies of DA effects have found that performing a concurrent activity at the encoding stage of memory leads to large decrements in later recall (Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Kellog, Cocklin, & Bourne, 1982; Park, Smith, Dudley, & Lafronza, 1989). Performing a second activity at the retrieval stage of memory, however, has yielded conflicting results. In some studies (Dywan & Jacoby, 1990; Moscovitch, 1994; Park et al., 1989), DA at retrieval led to a decrement in memory performance, although not as severe as that associated with DA at encoding. In other studies, however, DA at retrieval had little effect on memory performance (Baddeley et al., 1984; Craik et al., 1996), leading Baddeley et al. to conclude that retrieval is an automatic process. The present experiments were designed to investigate why dividing attention at the retrieval stage of memory has had a variable effect on recall performance, and in doing so to uncover the conditions under which such effects are produced.

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It is surprising that DA would have such a large and consistent effect at encoding, but a variable and sometimes much smaller effect at retrieval. The existence of an asymmetry between encoding and retrieval is unexpected from the perspective of theories of memory that posit a substantial overlap between the two processes. Tulving's (1983) encoding specificity principle as well as the transfer appropriate processing theory (Roediger, Weldon, & Challis, 1989) are cases in point. Similarly, Kolers's (1973) proceduralist view suggests that individuals remember in terms of the operations or activities of encoding, and hence the two should be linked. If encoding and retrieval processes are indeed similar, experimental conditions that affect one set of processes should have a similar effect on the other set, and not different effects as some studies have found.

In attempting to solve this puzzle, Moscovitch and Umilta (1990, 1991; see also Moscovitch, 1992, 1994) offered a neuropsychological account of the effects of DA on memory. They proposed a component-process model, whereby performance on explicit tests of memory is mediated by two main components: (a) an associative cue-dependent component that is modular and requires medial temporal lobe/hippocampal (MTL/H) and diencephalic structures, and (b) a strategic component that requires the prefrontal cortex (PFC), a central system that is under voluntary control.

Being modular, the first component is domain specific and operates mandatorily and automatically at encoding and retrieval. At encoding, this component indiscriminately picks up any information that is consciously apprehended and binds only that information into a memory trace. The strategic PFC component is needed to control this modular system and organize the information it receives and emits. At encoding, it helps direct attention to the information that serves as the input to the MTL/H system. As such, it is more resource demanding than the modular process. Any concurrent task that diverts cognitive resources, by dividing attention during encoding, decreases the likelihood of that information being encoded adequately by the MTL/H system, leading to poor memory (Bentin, Moscovitch, & Nirhod, 1998).

At a neuronal level, the memory trace consists of the neural elements that mediate the conscious experience at encoding. These include elements in the posterior neocortex (and perhaps elsewhere) that form the perceptual representation systems and are responsible for the content of the experience. Also included are whatever neural elements that made the experience conscious, thus forming a consciousness-content packet bound together by the MTL/H neurons (Moscovitch, 1995). At retrieval, any cue that is consciously apprehended obligatorily interacts with the memory trace via the MTL/H if it is associated with it, in a process known as *ecphory*. The product of that interaction is then delivered automatically to consciousness and experienced as a memory.

When the necessary cues are made available, the ecphoric process mediated by the MTL/H is executed mandatorily and automatically. A concurrent task can only interfere with memory retrieval 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; it also is needed to initiate a memory search, implement retrieval strategies, and monitor the output from the MTL/H to determine its veridicality and consistency with the goals of the memory task (see also Burgess & Shallice, 1996). Thus, performing a concurrent task at retrieval leads to impaired memory only on memory tests that require substantial involvement of the resource-demanding PFC component. If the frontal lobe contribution for the memory test is minimal, then interference at retrieval is small or even nonexistent (Moscovitch, 1994).

In studies in which interference effects were observed from DA at retrieval, all used memory tests that are sensitive to frontal lobe damage. Patients with frontal lobe damage or dysfunction have been shown to perform poorly on tests of free recall of categorized lists (della Rocchetta, 1986; Dywan & Jacoby, 1990) and memory tests that require list differentiation (Moscovitch, 1982). Consistent with the model's predictions, recall of categorized word lists (Moscovitch, 1994; Park et al., 1989) and recognition that required list discrimination or source monitoring (Dywan & Jacoby, 1990; Jacoby, 1991) were disrupted when a concurrent task was performed at retrieval.

In other studies, where interference effects were much smaller or even nonexistent (Baddeley et al., 1984; Craik et al., 1996), the memory test consisted of free recall, cued recall or recognition of a list of unrelated words. As Moscovitch and Umilta (1991) suggested, these tests are sensitive to hippocampal rather than frontal lobe damage. That is, performance on these tests is most often disrupted by hippocampal damage but much more rarely by frontal damage (Milner, Petrides, & Smith, 1985; Moscovitch, 1982; Schacter, 1987). As the component-process model suggests, if the frontal lobe contribution to the memory test is minimal, then interference effects at retrieval should be small, because it can be performed by the modular MTL/H system, which operates obligatorily and automatically.

Although the component-process model accounts for the asymmetry of DA effects at encoding and retrieval, as well as for the variability of effects at retrieval, recent studies by Craik et al. (1996) and Anderson, Craik, and Naveh-Benjamin (1998) question one of the model's assumptions. Craik et al. found that dividing attention during retrieval of a list of unrelated words led to only a slight decrease in number of words recalled, but a marked increase in reaction time (RT) on the concurrent task. They concluded that retrieval on their memory test was resource demanding, as indexed by the large RT costs, yet was obligatory and immune to disruption because free recall was relatively unaffected by the concurrent task. Although consistent with the model's claim that ecphoric retrieval processes are obligatory, their findings suggest that they are also resource demanding (nonautomatic).

Whereas ecphory is considered to be mediated by MTL/H, establishing retrieval mode is mediated by the PFC, as recent functional neuroimaging studies have shown (Kapur et al., 1995; Schacter, Alpert, Savage, Rauch, & Albert, 1996). Establishing and maintaining a retrieval mode activates the PFC, and as suggested by Craik et al. (1996), may be the resource-demanding component of retrieval. Before considering this interpretation in more detail in the General Discussion, we consider the possibility that DA can reduce memory performance (not just concurrent task performance) on tests of memory that are not primarily dependent on PFC resources, such as those used by Baddeley et al. (1984) and Craik et al. (1996).

An important factor that may influence whether DA has an effect on memory is the nature of the concurrent task. Martin, Wiggs, Lalonde, and Mack (1994) showed that the type of concurrent task performed at retrieval can influence memory performance. Similar to the Moscovitch (1994) study, they looked at letter and category fluency. Letter fluency is known to be negatively affected by frontal damage (Benton, 1968; Monsch et al., 1994), whereas category fluency is affected more by temporal lobe damage (Newcombe, 1969). In their study, they considered the effects of performing a finger tapping or object decision task concurrently with each fluency test. On the basis of neuropsychological evidence, they presumed that an object decision task (Kroll & Potter, 1984) was more dependent on temporal lobe function and that finger tapping was more dependent on frontal function. Martin et al. replicated Moscovitch's (1994) findings, with finger tapping interfering much more with letter than category fluency. Furthermore, they showed that the object decision task interfered more with category than letter fluency. Thus, they provided evidence that letter and category fluency, believed to be dependent on frontal and temporal lobe function respectively, were differentially disrupted by concurrent tasks believed to require the same resources and neural systems as each of the fluency tests. These studies suggested to us that interference effects at retrieval may depend on the type of memory test that is used, as well as the type of concurrent task that is chosen.

Looking now at the component-process model, it is possible to derive two testable hypotheses about the type of concurrent task that might affect retrieval. If two tasks, in a

DA paradigm, require access to the MTL/H system (needed to reactivate the neocortical representation), interference may occur on one or both tasks. Similarly, if the two tasks compete for the perceptual representational system 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 LTM, short-term memory (STM), or simply perception.

The model also assumes that encoding requires PFC strategic resources to help direct attention and organize the information that serves as the input to the MTL/H system. A prediction that follows from this is that any concurrent task that diverts conscious awareness away from encoding also decreases the likelihood of those items being received by the MTL/H system, leading to poor memory. Thus, all tasks performed concurrently at encoding, that are equally attention demanding, should disrupt memory to a similar degree.

Our purpose in the present series of experiments was to investigate the precise conditions under which DA, at either encoding or retrieval, interferes with performance on memory tests that do not rely primarily on the strategic PFC system. The first experiment was designed to determine whether substantial interference effects could be obtained under DA at retrieval, and if so, whether they depended on competition for memory structures. We then describe experiments designed to explore whether interference effects, created under DA at retrieval, depend on competition for representational structures. If either of these conditions leads to decrements in memory performance, it would suggest that retrieval is neither an automatic (cf. Baddeley et al., 1984) nor an obligatory process (cf. Baddeley et al., 1984; Craik et al., 1996), and it also would outline those conditions under which DA at retrieval can interfere with memory. Finally, in order to gain a better understanding of encoding and retrieval processes, we compare the size of the interference effect when attention is divided during either of these processes.

Experiment 1

We designed the first experiment to determine whether substantial interference can be obtained at retrieval, and if so, whether it depends on competition for memory structures, as suggested by the component-process model. Neuropsychological research on memory retrieval points to a role for the hippocampus in mediating retrieval of items from LTM (Baddeley & Warrington, 1970; Milner, 1966; Scoville & Milner, 1957). Because STM is unaffected in patients with MTL/H lesions, it is assumed to be mediated by a different neural substrate, a fact corroborated by studies of patients with left midtemporal lesions who show the complementary patterns of impaired and preserved abilities (Shallice & Vallar, 1990; Warrington & Shallice, 1969).

If STM and LTM are subserved by different neural substrates, parallel processing could occur when the two are engaged concurrently. That is, we would expect less interference when an STM and LTM task are performed simultaneously, because neuropsychological and behavioral studies have shown that these two systems are dissociable (Glanzer & Cunitz, 1966; Milner, 1966; Murdock, 1962; Scoville & Milner, 1957), than when both concurrent tasks require LTM. The first experiment tests this prediction by asking participants to recall, out loud, a list of previously studied random words (an LTM task) while simultaneously performing another memory task, recognition. We compared the effects of two different recognition tasks, one believed to reflect STM and one believed to reflect LTM. The critical difference between the "short" and "long" versions of the recognition task was the number of intervening items between repeated words.

Tulving and Colotla (1970) stated that memory for a word can be attributed to primary (short-term) memory if no more than about seven other events (or words) have intervened between its presentation and recall. If more than about eight words have intervened, memory is attributed to secondary (long-term) memory. The number of intervening items used in the STM and LTM recognition tests in our study was chosen with this critical number in mind. In the short version of the recognition task, the number of intervening items was small; only 1–3 other words were presented before a repeated word occurred. In the long version of the recognition task, the number of intervening items was larger (9–11). Given that primacy and recency effects reflect LTM and STM respectively (Glanzer & Cunitz, 1966), performance on the long version of the recognition task was taken as a reflection of LTM, whereas performance on the short version was taken to reflect STM.

Although both the short and long recognition tasks require encoding as well as retrieval processes, in this experiment we were able to test only whether the latter recognition test would make relatively greater demands than the former, during retrieval, on the processes required for free recall. On the basis of neuropsychological studies and the component-process model, we ascribed a crucial retrieval process in free recall to the MTL/H and expected that if a concurrently performed recognition task can interfere with retrieval, it would do so when there is competition between the tasks for LTM structures (MTL/H). A comparison of the relative effects of a concurrently performed STM versus LTM recognition task allows us to examine the effects of competition for MTL/H structures. Furthermore, if any significant decrement in free recall performance is observed under DA at retrieval, it would suggest that retrieval is neither an automatic nor obligatory process.

Method

Overview of Experiment

Participants were asked to try to commit to memory an auditorily presented list of words; their recall of this list was the target memory task. After the encoding phase, they began one of the recognition tasks, presented visually on a computer screen. In the DA conditions, participants continued to perform the recognition task while simultaneously trying to recall out loud the target task word list. In the full attention condition, the recognition task ended prior to recall performance.

Participants

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 hearing. The mean age of participants was 20.3 (SD = 1.8).

Materials

Stimuli for the target memory tasks were 64 unrelated common nouns. Four lists of 16 randomly chosen words were created. Stimuli for the recognition tasks were 240 unrelated nouns or adjectives. Six lists of 35 words were created for the recognition tasks. Fifteen of the 35 words were chosen randomly, to be repeated in the list, making each list 50 words long. Two more lists of 15 words were also created, with 5 randomly chosen words repeated to make each list 20 words long. These shorter lists were required for the full attention condition (see the *Procedure* section). Six orders of presentation were created for the experimental conditions, and two orders were created for the recognition task baseline measures (single-task performance).

All stimuli were medium- to high-frequency two-syllable words taken from the *Frequency Analysis of English Usage* (Francis & Kucera, 1982). Word frequencies ranged from 26 to 100 occurrences per million. All lists were matched with respect to word frequency.

Experimental Tasks

Target recall task. Words for the target memory task were recorded in a soundproof booth onto an audio file using the Sound Designer II (Avid Software, Palo Alto, California) program. Four word lists were created by randomly choosing 16 words, for each list, from the original 64 words. Each word list was created with 3 s 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 on a cassette player.

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 digit at the end of each word list and were instructed to count backwards by threes aloud. The digits were recorded onto the audio tape in the same manner as the words for the target memory task.

Recognition tasks. For each recognition task, a list of 50 words was presented visually on the computer screen at a rate of 1 word every 2 s. For each word, participants indicated whether it had appeared earlier in the list by pressing one of two keys on the keyboard using their dominant writing hand.

There were two versions of the recognition task: one with only a few intervening items before repeated words (STM task) and one with a much longer delay before a word is repeated (LTM; see introduction to Experiment 1). For each task, participants were told to study each word in the list as it occurred, because they would have to recognize if the word was repeated, either shortly after being presented or after many intervening items for the short and long versions, respectively. For both the short and long versions, 15 of the 35 words were repeated. The lists were made such that one third (5) of the repeated words were displayed in the first 40 s of the recognition task, and the remaining two thirds (10) were displayed in the last 60 s.

CRT Task

To determine whether the short and long recognition tasks were equally difficult or resource demanding, an auditory continuous reaction time (CRT) task was used: 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 hit 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 hit a key or after 3 s 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 short and long versions of the recognition task. For the DA conditions, in order to avoid having participants make different manual keypress responses for the CRT and concurrent tasks, participants made a verbal response for each word: "no" for new words and "yes" for repeated words. The experimenter recorded the participants' verbal responses on a separate keyboard. In the DA conditions, the tone task was performed alone for a short time, after which one of the recognition tasks began and lasted 100 s. The RT and number of correct responses in the auditory CRT were thought to gauge how demanding each recognition task was, with longer RTs indicating greater demands.

Procedure

Practice session. Participants were tested individually. In the practice phase, participants performed the target memory task and each of the recognition tasks alone. The study phase for the target task was identical in the practice and experimental phase except that different lists were studied for each. Participants heard a tape recorded female voice reading a list of 16 words. Participants were asked to try to commit the taped 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 s to eliminate recency effects (as in Craik et al., 1996). In the practice phase, recall of the studied words occurred immediately following the arithmetic task. Participants had 60 s for free recall. Participants were then given a practice session for the short and long recognition tests.

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

Following the first single-task recognition measure, the three experimental conditions (full attention plus two DA conditions) were administered. Presentation of the words for the target recall task was followed by the arithmetic task, then either the short, long, or mixed version (see below) of the recognition task began. The recognition task was performed alone for 40 s until the computer emitted a low-pitched tone. The tone signaled that recall of taped words should begin. For the two DA conditions, the short or long recognition task continued on the computer while participants simultaneously tried to recall words for the target task. The

[1] One participant was excluded from Experiment 1 because his accuracy rate on the long recognition task was zero in the DA condition. An additional participant was tested in his place.

recognition and target memory tasks were performed simultaneously for 60 s. For each DA condition, a perfect score on the recognition task would involve identifying all 10 of the repeated words. Participants were told to divide their efforts equally between the recognition and target memory task. The importance of placing 50% of their efforts on the recall task and 50% on the recognition task was emphasized. After recall in the DA conditions, the experimenter asked participants if they recalled any additional words from the target memory task, now that they did not have to do two things simultaneously. Responses were tape recorded.

In the full attention experimental condition, the recognition task terminated after the computer signaled that free recall should begin. The recognition task in this condition was a mixed version of the short and long recognition tasks, with some of the words repeated after a short delay and some after a long delay. In this condition recall occurred under full attention. For all orders of experimental conditions, participants were given a 4-min break before beginning the next condition.

For each participant, the final phase of the experiment involved performing three sessions of the auditory CRT task alone and concurrently with the short and long versions of the recognition task. The order of the sessions was counterbalanced across participants.

Results

Target Memory Task

Both the short and long recognition tasks interfered substantially with free recall performance. The means for each condition are presented in Table 1. The mean percentage decline in recall performance was slightly larger in the long compared to short DA condition, although this difference was not significant. The data were analyzed according to a 2 (between-subject: order of experimental condition and order of single-task recognition measure) × 1 (within-subject: experimental condition) analysis of variance (ANOVA). There were no significant main effects or interactions with the order factors on target task performance.

Table 1
Experiment 1: Number of Words Recalled, Percentage Decline From Full Attention, and Accuracy Rates in Each Condition

Measure and condition	*M*	*SD*
Target memory task		
Words recalled		
Full attention	8.75	2.15
DA short	5.88	2.31
DA long	5.46	2.21
Percentage decline		
DA short	31	24
DA long	37	21
Recognition tasks accuracy rates		
Baseline short	.69	.17
DA short	.39	.21
Baseline long	.62	.14
DA long	.26	.17
Mixed	.74	.22

Note. DA = divided attention.

There was a main effect of experimental condition, $F(2, 46) = 28.80$, $MSE = 2.68$, $p < .001$. Planned comparisons showed the mean number of words recalled in both the short and long DA conditions differed significantly from the mean in the full attention condition, $F(1, 23) = 29.89$, $MSE = 6.64$, and $F(1, 23) = 61.69$, $MSE = 4.22$, respectively, $ps < .001$. The difference in number of words recalled between the short and long conditions did not differ significantly, $F(1, 23) = 0.80$, $MSE = 5.21$, $p = .38$. The mean percentage decline in the DA conditions compared to the full attention condition are also shown in Table 1.

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 number of additional words recalled after the short and long DA conditions was only 0.50 ($SD = .72$) and 0.83 ($SD = 1.20$), respectively.

Recognition Tasks

Accuracy rates for both the short and long recognition tasks, in the DA conditions, were much worse than in the respective single-task conditions. The recognition task costs (single − dual task performance) were larger in the long compared to the short DA condition, but the difference was not significant. The data were analyzed according to a 2 (between-subject: order of experimental condition and order of single-task recognition measure) × 1 (within-subject: experimental condition) ANOVA. There were no significant main effects or interactions with the order factors on recognition task performance. There was a main effect of experimental condition, $F(3, 54) = 45.79$, $MSE = 0.02$, $p < .001$. The mean accuracy rates for identifying repeated words for each condition are presented in Table 1. The difference in accuracy rates for the short and long recognition tasks performed under DA conditions was significant, $t(23) = 3.67$, $p < .05$, but recognition task costs did not differ, $t(23) = -1.04$, $p > .05$. Planned comparisons showed the mean accuracy rate in both the short and long DA conditions differed significantly from their respective single-task baseline conditions, $F(1, 23) = 51.33$, $MSE = 0.04$, and $F(1, 23) = 65.73$, $MSE = 1.07$, respectively, $ps < .001$.

Analysis of Correlations

The correlation between the percentage decline in number of words recalled for the target memory task and the accuracy rate cost (single − dual condition) for the short and long recognition task was not significant, $r = -.29$, $p = .16$, and $r = .33$, $p = .06$, respectively.

Auditory CRT

Recognition task. The accuracy rate for both of the recognition tasks suffered to a similar degree when the auditory CRT task was performed concurrently. The mean accuracy rates for the short and long recognition tasks, performed concurrently with the CRT tone task, was .31 ($SD = .19$) and .24 ($SD = .18$), respectively. The difference between these two accuracy rates did not reach significance, $t(23) = 1.96, p > .05$. There was no effect of task order on accuracy rates for either the short or long recognition tasks.

CRT tone task. The difference in the number of tones correctly identified in the short and long DA conditions reached significance, $F(1, 23) = 5.47$, $MSE = 47.52$, $p < .05$. The mean correct responses for each condition are presented in Table 2. A within-subject ANOVA revealed a main effect of condition, $F(2, 46) = 86.42$, $MSE = 124.79$, $p < .001$. There was no effect of order on number of correct responses; the Condition × Order interaction was also nonsignificant. Planned comparisons revealed that the number of tones correctly identified in both the short and long DA conditions differed significantly from the full attention condition, $F(1, 23) = 81.23$, $MSE = 361.09$, and $F(1, 23) = 103.24$, $MSE = 340.11$, respectively, $ps < .0001$.

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-subject ANOVA revealed a main effect of condition, $F(2, 23) = 27.62$, $MSE = 10{,}999.65$, $p < .001$. There were no other significant main effects or interactions.

Planned comparisons showed that the mean RT in both the short and long DA conditions differed significantly from the mean in the baseline condition, $F(1, 23) = 30.35$, $MSE = 29{,}756.03$, and $F(1, 23) = 32.43$, $MSE = 28{,}357.66$, respectively, $ps < .001$. The difference in RT between the short and long conditions did not differ significantly, $F(1, 23) = 0.01$, $MSE = 7{,}884.19$, $p = .92$, suggesting that the two tasks make similar resource demands.

Discussion

The major findings from this experiment were that memory performance was affected substantially by a concurrent recognition task and that the STM and LTM DA conditions did not produce different amounts of interference. Each of these findings is discussed in turn. The magnitude of the interference effects, on free recall of a list of random words, was much larger than that found in other DA studies using a similar memory task. For example, Baddeley et al. (1984) found virtually no decrease in recall performance in their DA conditions compared to full attention. Similarly, using different methodological procedures, Craik et al. (1996) found a maximum decrease of only 13% on performance in their DA condition. The decreases in recall performance in the present study, 31 and 37% in the short and long DA conditions respectively, were much higher than in other studies, whereas the recognition task performance showed a drop in performance levels that was similar to that seen on concurrent tasks from other DA studies (Craik et al., 1996; Johnston, Greenberg, Fisher, & Martin, 1970).

The substantial decrements in memory, observed under DA, call into question the hypothesis that retrieval is obligatory as proposed by Craik et al. (1996). Instead, these results suggest that memory can be impaired under certain DA conditions. Nevertheless, consistent with the Craik et al. (1996) and Johnston et al. (1970) studies, concurrent task performance in this experiment was impaired considerably in the DA conditions. Retrieval, therefore, cannot be an automatic process as proposed by Baddeley et al. (1984); it is in fact resource demanding, as indexed by the poorer recognition task performance in both DA conditions.

Johnston et al. (1970) suggested that performance of the concurrent task may be an inverse function of the difficulty of the target memory task. In the present experiment, however, trade-offs between the target memory and recognition task performance do not appear to be a factor in determining performance levels, because the correlations between the two were not significant. In summary, our results suggest that memory retrieval is neither obligatory nor automatic.

Experiment 1 was also conducted to determine whether interference during retrieval of the target word list would be greater when the concurrent recognition task also involved LTM than when it involved only STM, as hypothesized by the component-process model. Our results indicate that interference effects are not different in these two conditions.

To check that the two recognition tasks were equally demanding, independent of their effects on memory, we considered their effects on an auditory CRT test. Both the short and long recognition tasks led to a similar increase in RT to correctly identify tones, when compared to the full-attention baseline condition. Thus, the auditory CRT task shows that the resources demanded by the STM and LTM recognition tests did not differ from each other.

Because the STM recognition task led to as much interference as the LTM one, competition for structures mediating LTM does not appear to be the source of the substantial DA effect. In terms of the component-process model, the results suggest that there are conditions under which DA disrupts retrieval, but the locus of the interference effect is not at the level of the MTL/H. Because the recognition task and the target memory task both involved verbal material, it is possible that they competed for access to a common representational system, leading to interference. Another possibility is that both recognition tasks are much more resource demanding than concurrent tasks used in other studies where interference effects on memory were smaller. The first alternative is tested in Experiments 2 and 4 and the second alternative in Experiment 3.

A puzzling finding from Experiment 1 was that participants recalled very few additional words from the target word list, even when the recognition task ended. Forgetting

Table 2
Experiment 1: Number of Correct Responses and Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition

	Correct response		Reaction time	
Condition	*M*	*SD*	*M*	*SD*
Baseline	102.21	27.33	716.83	162.78
DA short	67.25	17.33	910.82	209.31
DA long	63.96	15.29	912.58	194.96

Note. DA = divided attention.

may have occurred either because the recognition task displaced memory for the target word list, or because memory for these words was weakened by the demands of the verbal-based recognition task, and retrieval cues are necessary to prompt memory. This issue is discussed later in the article, after we consider whether the finding occurred reliably in the subsequent experiments.

Experiment 2

The following experiment investigated why the effects of DA at retrieval were larger in Experiment 1 than those found in other studies that also examined free recall of a list of unrelated words (Baddeley et al., 1984; Craik et al., 1996). It is possible that large interference effects at retrieval are found only when the concurrent tasks both require memory, be it recall or recognition, STM or LTM. Alternatively, as suggested by the component-process model, interference might arise because participants have difficulty performing two tasks that both require activation of the same verbal representational system. To test this hypothesis we administered a word-monitoring task, concurrently at retrieval, in which recognition memory was not necessary, but which maintained verbal processing demands similar to Experiment 1.

The concurrent task was changed from recognition to word monitoring, an analogue of the digit-monitoring task used in other studies (Jacoby, Woloshyn, & Kelley, 1989; Park et al., 1989). If the memory demands of the recognition task in Experiment 1 were responsible for the large interference effects on memory retrieval, then word monitoring in Experiment 2 should produce less interference. Monitoring only requires participants to keep a tally of the number of items that meet the required criterion, rather than remembering the items themselves. If, however, accessing verbal representations for the target memory and concurrent task led to the large DA effect, then Experiment 2 should produce similarly large amounts of interference as in Experiment 1 because the verbal component of the concurrent task was maintained.

Two different types of word-monitoring tasks were used, a semantic one and a phonological one. The semantic task consisted of monitoring for successive words that denoted man-made objects, whereas the phonological task required monitoring for successive words consisting of two syllables. We are aware that word monitoring does not completely eliminate the memory component of the concurrent task, but if competition for MTL/H memory structures is the source of the large interference effect, then we would expect the effect to be related to the level of processing required by the monitoring task. That is, because semantic processing leads to better memory than phonological processing (Craik & Lockhart, 1972), the MTL/H system may be preferentially engaged by the former and thus lead to greater interference under DA at retrieval, if the locus is at this source. If the two monitoring tasks do not lead to different amounts of interference, then the component-process model suggests that the locus of interference is at the level of the representational system.

Method

Participants

Participants were 24 naive undergraduate students at the University of Toronto who received $10 for their participation.[2] All participants claimed to be native English speakers and to have normal or corrected-to-normal vision and hearing. The mean age of the participants was 22.3 (SD = 2.06).

Materials

Stimuli for the target memory tasks were the same as those used in Experiment 1. Stimuli for the word-monitoring tasks were 340 words.

Man-made words. Three 50-word lists, consisting of words representing animals (e.g., *giraffe*) and man-made objects (e.g., *table*), were created from the pool of 340 words. These lists were created such that 9 sets of 3 man-made words in a row occurred throughout each list. A 20-word list was created such that 3 sets of 3 man-made words in a row appeared throughout the list.

Two-syllable words. Three other 50-word lists consisting of one-, two-, and three-syllable words (e.g., *tree, hammer,* and *radio,* respectively) were also created. These lists were created such that 9 sets of 3 two-syllable words in a row occurred throughout each list. A 20-word list was created such that 3 sets of 3 two-syllable words in a row appeared throughout the list.

All stimuli were medium- to high-frequency words chosen from Francis and Kucera (1982). Word frequencies ranged from 26 to 100 occurrences per million.

Experimental Tasks

Target recall task. For the recall task, the materials and procedure were the same as those used in Experiment 1.

Monitoring task. Participants viewed a list of words presented on the computer screen at a rate of 1 word every 2 s. There were two versions of the monitoring task: man-made and two-syllable. For the man-made version, participants were told to press a key only when they noticed that 3 man-made words were presented in a row among a list of animal and man-made words. For the two-syllable version, participants were told to press a key only when they noticed that 3 two-syllable words were presented in a row among a list of one-, two-, and three-syllable words. The lists were made such that one third (3) of the sets occurred during the first 40 s of the monitoring task, and the remaining two thirds (6) occurred in the last 60 s.

CRT task. The auditory CRT task used in Experiment 1 was used in this study. The auditory tone task was performed alone for a baseline measure and in DA conditions with the man-made and two-syllable monitoring tasks.

Procedure

Practice session. The practice session was the same as that used in Experiment 1 except that the concurrent tasks were the man-made and two-syllable tasks.

[2] Several participants were excluded from Experiment 2: Five participants did not know what syllables were, three participants had accuracy rates of zero on at least one of the monitoring tasks in the DA condition, and two participants' baseline target recall task score was much lower than either DA condition. Additional participants were tested in their place.

Experimental sessions. The procedure for measuring single-task performance for each monitoring task as well as for the experimental (DA) conditions was the same as in Experiment 1, except that the recognition tasks were replaced with the semantic and phonological monitoring tasks.

It should be noted that in the full attention experimental condition, a filler task, either the man-made or two-syllable version of the monitoring task, was performed for the first 40 s after the study phase of the target word list. Thus, the time lag (between when the words for the recall task were studied) and the requirement of performing 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. In this condition, participants recalled words under full attention for 60 s.

As in Experiment 1, the final phase of the experiment involved performing three sessions of the auditory CRT task (full attention baseline and two DA conditions). The order of presentation of the DA conditions was counterbalanced across participants.

Results

Target Recall Task

Changing the memory load requirement in the concurrent tasks did not alter the magnitude of the interference effect on free recall performance. Table 3 shows the number of words recalled in each DA condition and the mean percentage decline from full to DA conditions. As in Experiment 1, there was a significant decline from full attention performance on recall and on monitoring performance in each DA condition. The data were analyzed according to a 3 (between-subject: order of experimental condition, type of filler task in the "full attention" condition, and order of single-task monitoring measures) × 1 (within-subject: experimental condition) ANOVA. There were no significant main effects or interactions with the order and filler task factors on target task performance. There was a main effect of experimental condition, $F(2, 46) = 38.50$, $MSE = 2.17$, $p < .0001$.

Table 3
Experiment 2: Number of Words Recalled, Percentage Decline From Full Attention in Each Condition, and Monitoring Task Accuracy Rates

Measure and condition	*M*	*SD*
Target memory task		
Words recalled		
Full attention	8.88	2.79
DA man-made	5.54	2.30
DA syllable	5.75	1.87
Percentage decline		
DA man-made	37	20
DA syllable	33	19
Monitoring tasks accuracy rates		
Baseline man-made	.69	.15
DA man-made	.42	.24
Baseline syllable	.68	.20
DA syllable	.38	.20
Filler	.76	.26

Note. DA = divided attention.

Planned comparisons showed the mean number of words recalled in both the man-made and two-syllable DA conditions differed significantly from the mean in the full attention condition, $F(1, 23) = 65.71$, $MSE = 4.06$, and $F(1, 23) = 46.22$, $MSE = 5.07$, respectively, $ps < .0001$. The difference in number of words recalled, between the man-made and two-syllable DA conditions, was not significant, $F(1, 23) = 0.27$, $MSE = 3.91$, $p = .61$.

Following each DA condition, participants were given the chance to recall words from the target task under full attention, but few participants recalled any additional words. The number of additional words recalled after the man-made and two-syllable DA conditions were only 0.38 ($SD = 0.65$) and 0.54 ($SD = 1.18$), respectively.

Monitoring Task

There was a significant decrease in performance on the monitoring task in each DA condition, compared to single-task baseline performance. Accuracy rates for both the man-made and two-syllable monitoring tasks in the DA conditions were much worse than their respective single-task baselines. The mean accuracy rates for each condition are presented in Table 3. The data were analyzed according to a 3 (between-subject: the two order factors and the type of filler task in the full attention condition) × 1 (within-subject: experimental condition) ANOVA. There were no significant main effects or interactions with the order and filler task factors on monitoring task performance. There was a main effect of experimental task condition, $F(3, 69) = 13.45$, $MSE = 0.05$, $p < .001$.

The difference in accuracy rates between the man-made and two-syllable DA conditions was not significant, $t(23) = 0.75$, $p = .46$. Moreover, the concurrent task costs (single − dual task performance for each task) did not differ, $t(23) = -.36$, $p > .05$. Planned comparisons showed the mean accuracy rate in both the man-made and two-syllable DA conditions differed significantly from their respective single-task baseline conditions, $F(1, 23) = 14.18$, $MSE = 0.12$, and $F(1, 23) = 31.48$, $MSE = 0.07$, respectively, $ps < .001$.

Analysis of Correlations

The correlation between the percentage decline in number of words recalled for the target memory task and the accuracy rate cost (single − dual condition) for the man-made and two-syllable monitoring task was not significant, $r = -.17$, $p = .42$, and $r = -.07$, $p = .77$, respectively.

Auditory CRT

Monitoring task. The accuracy rate for both of the monitoring tasks suffered when the auditory CRT task was performed concurrently.[3] The mean accuracy rates in the

[3] The data from only 23 participants are included in this analysis. Because of experimenter error, the data for one participant were lost.

man-made and two-syllable DA conditions were .49 (SD = .20) and .36 (SD = .20), respectively. The difference between these two accuracy rates was significant, $t(23) = 2.72$, $p < .05$. There was no effect of task order on accuracy rates for either the man-made or two-syllable concurrent tasks.

CRT tone task. The difference in number of tones correctly identified, between the man-made and the two-syllable DA condition, was significant, $F(1, 22) = 5.46$, $MSE = 98.15$, $p < .05$. The mean number of correct responses for each condition are presented in Table 4. A within-subject ANOVA revealed a main effect of condition, $F(2, 44) = 88.88$, $MSE = 101.61$, $p < .001$. There was no effect of order on number of correct responses; the Condition × Order interaction was also not significant. Planned comparisons revealed the number of tones correctly identified in both DA conditions differed significantly from the full attention baseline condition, $F(1, 22) = 100.56$, $MSE = 229.15$, and $F(1, 22) = 108.39$, $MSE = 282.35$, respectively, $ps < .0001$.

The mean RT to identify tones is shown for correct responses only (see Table 4). As in Experiment 1, an outlier analysis eliminated RTs greater or lesser than two standard deviations from the mean for each participant in each condition. A within-subject ANOVA revealed a main effect of condition, $F(2, 44) = 27.63$, $MSE = 15{,}199.80$, $p < .0001$. There was no effect of order on RTs; the Condition × Order interaction was also nonsignificant.

Planned comparisons showed the mean RT in both the man-made and two-syllable DA conditions differed significantly from the mean in the baseline condition, $F(1, 22) = 28.93$, $MSE = 30{,}417.64$, and $F(1, 22) = 31.45$, $MSE = 49{,}167.74$, respectively, $ps < .0001$. The difference in RT between the man-made and two-syllable conditions also differed significantly, $F(1, 22) = 8.03$, $MSE = 255{,}495.14$, $p < .01$. The mean RT for the two-syllable DA condition was 1,013 ms, and for the man-made condition it was only 950 ms. Thus, the task in the two-syllable condition appears to be more difficult and requires more resources than the task in the man-made condition.

Discussion

There was a significant and equivalent interference effect on memory, created by both monitoring tasks, that was comparable to that observed in Experiment 1 under DA conditions. Because recognition memory for specific items was not required in word monitoring yet interference effects were still large, it is unlikely that interference arises from competition for a memory system mediated by the MTL/H. Because semantic processing leads to better memory than phonological processing, it should also have led to greater interference if competition for memory structures accounts for the effect. Our finding that interference was not significantly greater in the semantic than phonological condition argues against this possibility.

This conclusion, however, needs to be qualified somewhat in view of the finding from the auditory CRT task that measured concurrent task difficulty. The auditory CRT task showed that the two-syllable concurrent task was slightly more difficult or took up more resources than the man-made one. That is, participants' performance on the former task was poorer than on the latter, and the RT on the tone task was longer. This result perhaps reflects that many of the participants were unsure of or unpracticed at determining the number of syllables in a word. Despite the slightly greater difficulty of the syllable task, the interference effect it produced on recall was slightly less than that of the man-made task.

It is possible that had the two-syllable and man-made tasks been equally difficult or resource demanding, a greater difference in the size of the interference effect in favor of the man-made task would have emerged. This still leaves open the possibility that competition for memory structures contributes to DA effects. Another reason for proceeding with caution, before claiming that memory structures do not contribute to the interference effects, is that the words in both word-monitoring tasks may have been encoded into LTM, thereby activating the MTL/H, leading to the large effect. We address this issue further in Experiment 4.

Comparing the CRT data from Experiments 1 and 2, the accuracy scores for concurrent task performance are similar. The RTs are longer overall for Experiment 2, but the percentage increases from baseline in each DA condition are quite similar. Thus, the recognition and word-monitoring tasks appear to require roughly similar amounts of cognitive resources. These resources, however, may be substantially greater than those demanded by concurrent tasks in other studies; this may account for the much larger interference effects we observed under DA at retrieval. We consider the consequences of this possibility in the next experiment.

Table 4
Experiment 2: Number of Correct Responses and Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition

	Correct response		Reaction time	
Condition	*M*	*SD*	*M*	*SD*
Baseline	101.61	22.61	754.12	125.16
DA man-made	69.96	20.75	949.72	221.33
DA syllable	65.13	18.05	1,013.41	262.72

Note. DA = divided attention.

Experiment 3

In light of the large DA effects found in the first two experiments, we wished to revisit the question of the asymmetry of DA effects at encoding and retrieval. A consistent finding in previous studies is that interference effects at encoding were about three times as large as those at retrieval (Baddeley et al., 1984; Craik, 1983; Craik et al., 1996; Kellog et al., 1982). If the concurrent tasks we used in our experiments were simply more difficult than those used in other experiments, a similar threefold increase in interference should be observed when they are performed simultaneously during encoding. If such a sizable effect is not found, and the proportion of interference effects at encoding and retrieval is considerably reduced, it would suggest that factors other than concurrent task difficulty are responsible for the large interference effect we observed in Experiments 1 and 2.

In other words, the size of the interference effect from DA at encoding should be comparable in size to what others have found, even when different concurrent tasks are used. To test this hypothesis in the next experiment, we considered the effects of dividing attention at the encoding stage of a list of unrelated words, using the same word-monitoring tasks as in Experiment 2. According to the component-process model, successful encoding of information requires PFC resources; any concurrent resource-demanding task prevents items from being received by the MTL/H, leading to poor memory. As such, we expected that our word-monitoring tasks would lead to large interference effects, similar in size to what others have found (Baddeley et al., 1984; Craik et al., 1996; Kellog et al., 1982) using different concurrent tasks.

Method

Overview of Experiment

Participants were asked to try to commit an auditorily presented list of words to memory and to recall them later (target task). While they encoded these words in the DA conditions, they simultaneously performed a word-monitoring task. To make the time lag between encoding and retrieval of target task words the same as in the previous experiments, participants also performed the word-monitoring task after they had encoded the words (prior to the retrieval phase). In the full attention condition, target task words were encoded under full attention. In all conditions, recall occurred under full attention.

Participants

Participants were 24 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 hearing. The mean age of the participants was 21.8 (SD = 2.7).

Materials

Stimuli for the target recall tasks were the same as those used in Experiments 1 and 2. Stimuli for the monitoring tasks were the same as those used in Experiment 2 plus 28 additional words chosen from the *Frequency Analysis of English Usage* (Francis & Kucera, 1982), which were needed in order to make the monitoring task lists longer. These words satisfied the same criteria as the words in Experiment 2.

Experimental Tasks

Target recall task. For the recall task, the materials and procedure used were the same as those used in the other experiments (see Experiment 1, *Experimental Tasks*).

Monitoring task. As in Experiment 2 there were two versions of the monitoring task: a man-made and a two-syllable version. The participant's task was the same as in Experiment 2.

CRT task. The auditory CRT task used in this study was the same as the one used in Experiments 1 and 2.

Procedure

Practice session. The practice session was the same as that used in Experiment 2.

Experimental sessions. As in the other experiments, a measure of single-task performance for either the man-made or two-syllable task occurred before the experimental conditions. The measure of single-task performance for the remaining monitoring task was taken at the end of the final experimental condition.

Following this, the three experimental conditions were given. In this experiment, however, the DA condition occurred during the encoding rather than retrieval stage of the target task. In these DA conditions, a 32-item word list was presented visually on the computer screen whereas the words for the target task were heard auditorily using a cassette player. Participants were told that during the DA condition they were to divide their efforts equally between the target and distracting tasks. As in the other experiments, the importance of placing 50% of their attention on the target task and 50% on the concurrent task was emphasized. As in the other experiments, the encoding stage was followed by the arithmetic task for 15 s. To make the time lag between the encoding and recall stage for the target task the same as in the other experiments, the arithmetic task was followed by 40 s of the man-made or two-syllable task.

In the full attention condition, participants did not have to perform a monitoring task during the encoding phase. However, they still performed the arithmetic task, followed by 40 s of one of the monitoring tasks. In this way, the lag between the time when the words were studied and the performance of another task before recall was the same as in the DA conditions.

In all conditions, recall occurred under full attention. Throughout recall in all experimental conditions, the experimenter tape-recorded responses for later transcription. For all orders of experimental conditions, participants were given a 4-min break before beginning the next condition.

For each participant, the final phase of the experiment involved performing three sessions of the auditory CRT task. The order of presentation of the concurrent task was counterbalanced across participants.

Results

Target Recall Task

As expected, dividing attention with either the man-made or two-syllable tasks during encoding led to a significant decline in recall performance. The magnitude of the drop was similar in size to that found in other studies. The mean number of words recalled in each condition and the mean percentage decline from full to DA conditions are presented in Table 5. The data were analyzed according to a 3 (between-subject: order of experimental condition, type of filler task in the full attention condition, and order of single-task monitoring measures) × 1 (within-subject: experimental condition) ANOVA. There were no significant main

[4] Two participants were excluded from Experiment 3 because their accuracy rate on at least one of the monitoring tasks was zero in the DA condition. Additional participants were tested in their place.

Table 5
Experiment 3: Number of Words Recalled, Percentage Decline From Full Attention in Each Condition, and Monitoring Task Accuracy Rates

Measure and condition	*M*	*SD*
Target memory task		
Words recalled		
Full attention	9.17	2.58
DA man-made	4.13	1.51
DA syllable	4.21	1.89
Percentage decline		
DA man-made	53	16
DA syllable	52	23
Monitoring tasks accuracy rate		
Baseline man-made	.72	.15
DA man-made	.67	.24
Baseline syllable	.70	.16
DA syllable	.58	.27
Filler	.71	.26

Note. DA = divided attention.

effects or interactions with the order and filler task factors on target task performance. There was a main effect of experimental condition, $F(2, 46) = 85.80$, $MSE = 2.33$, $p < .0001$. Planned comparisons showed that the mean number of words recalled in both the man-made and two-syllable DA conditions differed significantly from the mean in the full attention condition, $F(1, 23) = 112.29$, $MSE = 5.43$, and $F(1, 23) = 93.62$, $MSE = 6.30$, respectively, $ps < .0001$. The difference between the man-made and two-syllable DA conditions in number of words recalled was not significant, $F(1, 23) = 0.07$, $MSE = 2.25$, $p = .79$.

Monitoring Task

There was no significant reduction in either man-made or two-syllable monitoring task performance under DA conditions with encoding. The mean accuracy rates for each condition are presented in Table 5. The data were analyzed according to a 3 (between-subject: the two order factors and the type of filler task in the full attention condition) × 1 (within-subject: experimental condition) ANOVA. There were no significant main effects or interactions with the order and filler task factors on monitoring task performance. Unlike the other experiments in this study, there was no main effect of experimental condition, $F(3, 69) = 1.87$, $MSE = 0.05$, $p = .14$.

The difference in accuracy rates between the man-made and two-syllable monitoring performance under DA conditions was not significant, $t(23) = 1.20$, $p = .24$, and monitoring task costs (single − dual task performance for each task) did not differ, $t(23) = -.83$, $p > .05$.

Planned comparisons showed that the mean accuracy rate in both the man-made and two-syllable DA conditions did not differ from their respective single-task baselines, $F(1, 23) = 0.62$, $MSE = 0.08$, $p = .44$, and $F(1, 23) = 2.79$, $MSE = 0.13$, $p = .11$, respectively.

Analysis of Correlations

The correlation between the percentage decline in number of words recalled for the target task and the accuracy rate cost for the man-made and two-syllable monitoring task was not significant, $r = .04$, $p = .84$, and $r = -.17$, $p = .43$, respectively.

Auditory CRT

Monitoring task. The accuracy rate for both of the monitoring tasks suffered to a similar degree when the auditory CRT task was performed concurrently. The mean accuracy rates for the man-made and two-syllable DA conditions were .42 ($SD = .16$) and .40 ($SD = .23$), respectively. The difference between these two accuracy rates was not significant, $t(23) = 0.47$, $p = .65$. There was no effect of task order on accuracy rates for either the man-made or two-syllable concurrent tasks.

CRT tone task. The number of tones correctly identified in both DA conditions differed significantly from the full attention baseline condition, and as in Experiment 2, the number of tones correctly identified in the man-made condition was significantly higher than in the two-syllable DA condition. The mean number of correct responses for each condition is presented in Table 6. A within-subject ANOVA revealed a main effect of condition, $F(2, 46) = 145.76$, $MSE = 64.19$, $p < .0001$. There was no effect of order on number of correct responses; however, the Condition × Order interaction was significant, $F(2, 44) = 6.56$, $MSE = 51.69$, $p < .01$. Planned comparisons revealed the number of tones correctly identified in both DA conditions differed significantly from the full attention baseline condition, $F(1, 23) = 122.26$, $MSE = 194.78$, and $F(1, 23) = 254.34$, $MSE = 124.85$, respectively, $ps < .0001$. Performance in the man-made condition differed significantly from the two-syllable DA condition, $F(1, 23) = 8.71$, $MSE = 65.51$, $p < .01$.

The mean RT to identify tones is shown for correct responses only (see Table 6). As in the previous experiments, an outlier analysis eliminated RTs greater or lesser than two standard deviations from the mean for each participant in each condition. A within-subject ANOVA revealed a main effect of condition, $F(2, 46) = 32.07$, $MSE = 11{,}412.31$, $p < .0001$. There was no effect of order on RTs; however, the

Table 6
Experiment 3: Number of Correct Responses and Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition

Condition	Correct response *M*	Correct response *SD*	Reaction time *M*	Reaction time *SD*
Baseline	112.92	19.52	707.43	140.82
DA man-made	81.42	17.03	911.36	235.92
DA syllable	76.54	15.16	930.04	200.35

Note. DA = divided attention.

Condition × Order interaction was significant, $F(2, 38) = 9.10$, $MSE = 7{,}964.25$, $p < .001$.

The RTs for each condition are shorter than in Experiment 2, but the percentage increases from baseline in each DA condition are similar. Planned comparisons showed the mean RT in both the man-made and two-syllable DA conditions differed significantly from the mean in the baseline condition, $F(1, 23) = 44.02$, $MSE = 521{,}465.03$, and $F(1, 23) = 64.92$, $MSE = 18{,}319.69$, respectively, $ps < .0001$. However, unlike in Experiment 2, the difference in RT between the man-made and two-syllable conditions was not significant, $F(1, 23) = 0.30$, $MSE = 27{,}481.78$, $p = .59$.

Comparison of Experiments 2 and 3

The data from Experiments 2 and 3 were re-analyzed using an ANOVA to compare the interference effects created under DA at retrieval and encoding, with experiment, order of experimental condition, type of filler task in the full attention condition, and order of single-task monitoring performance measures as between-subject factors. A separate analysis was carried out for the percentage decline in recall performance and monitoring task costs.

The main effect of Experiment on percentage decline in target memory task performance was significant, $F(1, 46) = 14.70$, $MSE = 497.9$, $p < .05$. The Condition × Experiment interaction was not significant, $F(1, 46) = 0.32$. The effect of a monitoring task performed concurrently at encoding on memory task performance was significantly larger than the effect at retrieval. This pattern did not differ for the man-made and two-syllable DA conditions.

In the analysis of monitoring task costs, the main effect of Experiment was significant, $F(1, 46) = 6.17$, $MSE = 0.145$, $p < .05$. The Condition × Experiment interaction was not significant, $F(1, 46) = 0.20$. Monitoring task costs were significantly smaller when performed at encoding as compared to retrieval. This pattern did not differ for the man-made and two-syllable DA conditions.

Discussion

Our major finding in the present experiment was that our semantic and phonological monitoring tasks produced interference effects at encoding that were comparable in size to those produced by concurrent tasks in other studies, even though our tasks led to much larger effects at retrieval (see Figure 1).

Note that in our study the average interference effects, across both the man-made and two-syllable DA conditions at encoding, were only about 17–18% greater than those at retrieval. In contrast, Craik et al. (1996) and Baddeley et al. (1984) used a similar memory task as we did but a different concurrent task, and they found a difference of 27–36%. The results of the present study suggest that there is nothing inherently more difficult about our monitoring tasks that is creating the larger interference effect on memory performance under DA at retrieval. If there were, then proportionately larger DA effects would have also been observed at encoding as at retrieval.

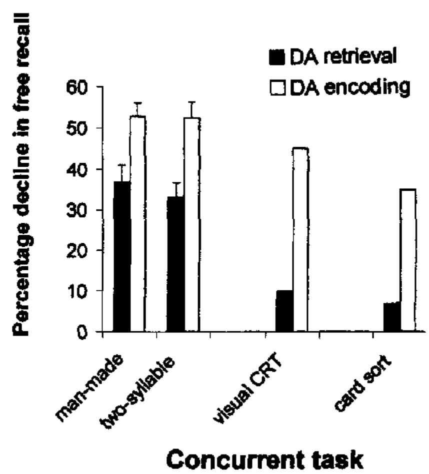

Figure 1. Mean percentage decline from full attention in free recall performance for divided attention (DA) at retrieval and encoding from Experiments 2 and 3 of the present study, visual continuous reaction time (CRT) of Craik et al. (1996, Experiment 1), and the card sort task of Baddeley et al. (1984).

In contrast, when the effects of DA on the monitoring task are examined, asymmetrical interference effects at encoding and retrieval are reversed: interference effects, measured as concurrent task costs, are substantial at retrieval but minimal at encoding (Craik et al., 1996; Johnston et al., 1970). Consistent with these findings, our results show that there was no significant decline in monitoring task performance in either the man-made or two-syllable DA conditions at encoding, but a substantial reduction at retrieval (see Figure 2).

Consistent with Craik et al. (1996) and Experiments 1 and 2, these results show that retrieval cannot be an automatic process, as Baddeley et al. (1984) claimed, because re-

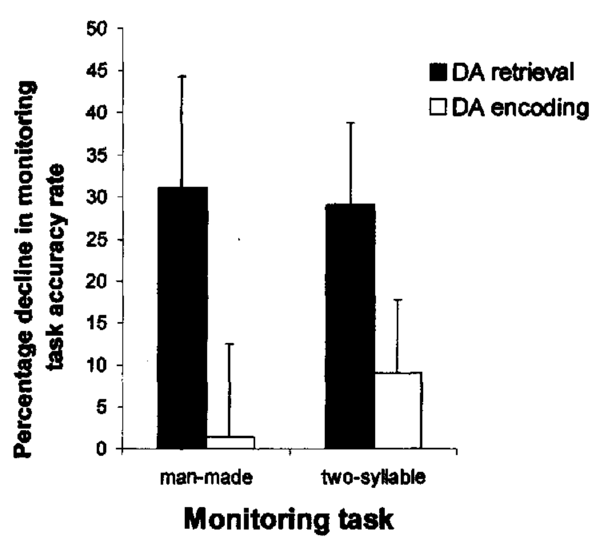

Figure 2. Mean percentage decline from single to divided attention (DA) conditions, in word-monitoring task performance, for Experiments 2 and 3.

sources were drawn away from the monitoring task, leading to poorer performance in the DA condition.

In the next experiment we tested directly the hypothesis derived from the component-process model, that large memory interference effects arise under DA at retrieval when the memory and concurrent task compete for the same representational system. We compared the magnitude of interference created under DA at retrieval by a monitoring task that uses either the same or a different type of material as the target memory task. As in the other experiments, free recall of a list of unrelated words was the target task, but either word monitoring or digit monitoring was the concurrent task.

Experiment 4

The following experiment was conducted to compare the size of interference produced under DA at retrieval by monitoring tasks that consisted of either the same or different material as in the target memory task. None of the past studies divided attention at retrieval using tasks that required access to the same type of representation as the target task. For example, in the Baddeley et al. (1984) study either card sorting or digit span was the concurrent task, and in the Craik et al. (1996) study a visual continuous RT test was performed concurrently with verbal memory tasks. Craik (1983) used card sorting together with a target task of verbal memory, and Kellog et al. (1982) tested memory for faces, when the concurrent task was numerical problems. In these studies interference effects on target memory task performance were quite large when attention was divided at encoding, but much smaller at retrieval. None of these studies found interference effects at retrieval that were as large as those observed in the present experiments.

Past research has shown that interference effects under DA at retrieval depend on the type of memory test that is used, as well as the type of concurrent task that is chosen (Martin et al., 1994; Moscovitch, 1994). A related hypothesis, derived from the component-process model, is that interference may occur at retrieval when the two tasks compete for a common perceptual representational system, responsible for the content of the memory trace.

If the large memory interference effects produced in Experiments 1 and 2 were due to competition for word-specific representational processes, then the magnitude of interference produced by a digit-monitoring task should be smaller than that produced by a word-monitoring task. Moreover, we are aware that our word-monitoring tasks from Experiments 2 and 3 have a memory component that may be contributing to the interference effects we observed on target memory performance. If the mnemonic component of our monitoring tasks is the factor leading to the large interference effects, then the size of the effect should remain large regardless of the type of material used in the monitoring task. If, however, the interference effect on memory differs depending on the type of material used in the monitoring task, then it would support the hypothesis that interference effects on memory, created under DA at retrieval, depend on the degree of competition for word-specific representational processes.

Method

Overview of Experiment

Participants were asked to try to commit an auditorily presented list of words to memory under full attention, and their recall was the target task. After the encoding phase, they began either a word- or digit-monitoring task presented visually on a computer screen. In the DA conditions, participants continued to perform the word- or digit-monitoring task while simultaneously trying to recall out loud the target task word list. In the full attention condition, the monitoring task ended prior to free recall.

Participants

Participants were 24 undergraduate students at the University of Toronto who received course credit for their participation.[5] All participants claimed to be native English speakers and to have normal or corrected-to-normal vision and hearing. The mean age of participants was 20.1 (SD = 1.4).

Materials

Stimuli for the target recall tasks were the same as those used in Experiments 1, 2, and 3. Stimuli for the word-monitoring task were the man-made word lists from Experiment 2. Stimuli for the digit-monitoring task were two-digit numbers chosen from a table of random numbers (Kirk, 1995). Three lists, 50 digits in length, were created by choosing a string of numbers, pseudorandomly, from the table. These number lists consisted of odd and even numbers. Each list was created such that nine sets of three odd numbers in a row occurred throughout each list. A 20-digit long list was created such that three sets of three odd numbers in a row appeared throughout the list.

Experimental Tasks

Target recall task. The free recall task was the same as in the other experiments (see Experiment 1, *Experimental Tasks*).

Monitoring tasks. The participant's task for the man-made task was the same as in Experiment 2. The odd-digit task involved the display of two-digit numbers presented visually on the computer screen at a rate of one digit every 2 s. Participants were told to press a key only when they noticed that three odd numbers were presented in a row among a list of even and odd numbers. As in the word-monitoring task, the number lists were made such that one third (3) of the sets occurred in the first 40 s of the monitoring task, and the remaining two thirds (6) occurred in the last 60 s.

CRT task. The auditory CRT task used in Experiments 1, 2, and 3 was used in this experiment.

Procedure

The practice and experimental sessions were conducted in the same manner as in Experiment 2, except that the two-syllable task was replaced by the odd-digit monitoring task.

For each participant, the final phase of the experiment involved performing three sessions of the auditory CRT task. The results of

[5] Several participants were excluded from Experiment 4: Five participants had accuracy rates of zero on the man-made monitoring task in the DA condition, and one participant had an accuracy rate of zero on the odd digits monitoring task in the DA condition. Additional participants were tested in their place.

Table 7
Experiment 4: Number of Words Recalled, Percentage Decline From Full Attention in Each Condition, and Monitoring Task Accuracy Rates

Measure and condition	*M*	*SD*
Target memory task		
Words recalled		
Full attention	7.88	2.15
DA man-made	5.38	2.00
DA odd-digit	6.67	2.20
Percentage decline		
DA man-made	30	25
DA odd-digit	13	24
Monitoring tasks accuracy rate		
Baseline man-made	.66	.26
DA man-made	.48	.20
Baseline odd-digit	.67	.23
DA odd-digit	.46	.24
Filler	.59	.30

Note. DA = divided attention.

this phase of the experiment are especially important in determining whether the digit- and word-monitoring tasks tie up similar amounts of processing resources.

Results

Target Recall Task

The magnitude of interference on free recall performance in the digit-monitoring DA condition was substantially smaller than that in the word-monitoring DA condition. This finding suggests the interference effects observed in Experiments 1 and 2 may be due to competition for word-specific processes. Table 7 shows the number of words recalled in each DA condition as well as the mean percentage decline from full to DA conditions. As in Experiment 2, there was approximately a 30% decline in recall performance when attention was divided at retrieval using the man-made monitoring task. The decline in recall performance when the odd-digit monitoring task was performed concurrently at retrieval was only 13%.

The data were analyzed according to a 3 (between-subject: order of experimental condition, type of filler task in the full attention condition, and order of measurement for single-task monitoring performance) × 1 (within-subject: experimental condition) ANOVA. There were no significant main effects or interactions with the order and filler task factors on target task performance. There was a main effect of experimental condition, $F(2, 46) = 20.15$, $MSE = 1.86$, $p < .0001$. Planned comparisons showed the mean number of words recalled in both the man-made and odd-digit DA conditions differed significantly from the mean in the full attention condition, $F(1, 23) = 41.07$, $MSE = 3.65$, $p < .0001$, and $F(1, 23) = 8.96$, $MSE = 3.91$, $p < .01$, respectively. The difference in number of words recalled between the man-made and odd-digit DA conditions was also significantly different, $F(1, 23) = 11.10$, $MSE = 3.61$, $p < .01$. The number of words recalled in the full attention condition did not differ depending on whether the filler task that preceded free recall was the man-made or odd-digit task, $t(23) = -1.04$, $p = .31$.

Following each DA condition, participants were given the chance to recall words from the target task under full attention. The number of additional words recalled after the man-made and odd-digit DA conditions was only 0.38 ($SD = 0.65$) and 0.89 ($SD = 1.18$), respectively.

Monitoring Tasks

Accuracy rates for the man-made and odd-digit monitoring tasks in the DA conditions were similar and much worse than in their respective single-task baseline condition. The mean accuracy rates for each condition are presented in Table 8. The data were analyzed according to a 3 (between-subject: the two order factors and the type of filler task in the full attention condition) × 1 (within-subject: experimental condition) ANOVA. There were no significant main effects or interactions with the order and filler task factors on monitoring task performance. There was a main effect of experimental condition, $F(3, 69) = 7.98$, $MSE = 2.64$, $p < .001$.

The difference in accuracy rates between the man-made and odd-digit DA conditions was not significant, $t(23) = 0.30$, $p = .77$. Moreover, monitoring task costs (single − dual task performance) did not differ, $t(23) = -0.37$, $p > .05$. Planned comparisons showed that the mean accuracy rate in both the man-made and odd-digit DA conditions differed significantly from their respective baseline conditions, $F(1, 23) = 10.27$, $MSE = 1.70$, and $F(1, 23) = 10.72$, $MSE = 2.29$, respectively, $ps < .01$.

Analysis of Correlations

The correlation between the percentage decline in number of words recalled for the target memory task and the accuracy rate cost for the man-made and odd-digit monitoring task was not significant, $r = -.19$, $p = .38$, and $r = -.13$, $p = .56$, respectively.

Auditory CRT

Monitoring tasks. The accuracy rate for both of the monitoring tasks suffered to a similar degree when the

Table 8
Experiment 4: Number of Correct Responses and Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition

	Correct response		Reaction time	
Condition	*M*	*SD*	*M*	*SD*
Baseline	96.58	21.38	782.46	133.38
DA man-made	73.88	17.84	945.94	209.75
DA odd-digit	76.79	18.02	933.94	196.00

Note. DA = divided attention.

auditory CRT task was performed concurrently. The mean accuracy rates for the man-made and odd-digit tasks under DA conditions were .38 ($SD = .24$) and .43 ($SD = .25$), respectively. The difference between these two accuracy rates was not significant, $t(23) = -.98$, $p = .34$. There was no effect of task order on accuracy rates for either the man-made or odd-digit monitoring tasks.

CRT tone task. The difference in number of tones correctly identified between the man-made and the odd-digit DA condition was not significant, $F(1, 23) = 2.74$, $MSE = 74.43$, $p = .11$. The mean number of correct responses for each condition is presented in Table 8. A within-subject ANOVA revealed a main effect of condition, $F(2, 46) = 38.74$, $MSE = 94.57$, $p < .001$. There was no effect of order on number of correct responses, and the Condition × Order interaction was also not significant. Planned comparisons revealed the number of tones correctly identified in both DA conditions differed significantly from the full attention baseline condition, $F(1, 23) = 42.75$, $MSE = 289.52$, and $F(1, 23) = 46.20$, $MSE = 203.48$, respectively, $ps < .0001$.

The mean RT to identify tones is shown for correct responses only (see Table 8). As in the previous experiments, an outlier analysis eliminated RTs greater or lesser than two standard deviations from the mean for each participant in each condition. A within-subject ANOVA revealed a main effect of condition, $F(2, 46) = 19.29$, $MSE = 10{,}330.22$, $p < .0001$. There was no effect of order on RTs, and the Condition × Order interaction was also nonsignificant.

Planned comparisons showed that the mean RT in both the man-made and odd-digit DA conditions differed significantly from the mean in the baseline condition, $F(1, 23) = 27.74$, $MSE = 23{,}118.75$, and $F(1, 23) = 21.61$, $MSE = 25{,}482.74$, respectively, $ps < .0001$. The difference in RT between the man-made and odd-digit DA conditions did not differ, $F(1, 23) = 0.26$, $MSE = 13{,}379.84$, $p = .62$, suggesting that the two monitoring tasks do not differ with respect to resource demands.

For all participants, the auditory CRT task was performed at the end of the experimental sessions. One might suggest that by this time participants had become well practiced at performing the man-made monitoring task, thereby decreasing this task's difficulty. To address this issue, we compared single-task performance from participants who performed the man-made task before the experimental sessions to those who performed it afterwards (see *Procedure*). We found no evidence of practice effects; mean single-task accuracy rates for each order was .66 and .65. Similarly, the single-task accuracy rate for the odd-digit task was not subject to practice effects, with means for each order of .68 and .67.

Discussion

Experiment 4 was conducted to compare the size of interference produced from DA at retrieval using monitoring tasks that consisted of either the same or different material as in the target memory task. The magnitude of the DA effect on free recall performance was significantly larger when the monitoring task involved words rather than digits. The memory interference effect produced when the digit- or word-monitoring task was performed concurrently with free recall was 13 and 30%, respectively. The greater decline in memory performance, in the word- versus digit-monitoring DA condition, is consistent with the hypothesis derived from the component-process model that interference can arise from competition for a common representational system.

The relatively smaller interference produced at retrieval by the digit-monitoring task suggests that it does not compete to the same degree as word monitoring for those representations necessary for verbal free recall. The small decline in memory performance observed in studies by Baddeley et al. (1984) and Craik et al. (1996) may have occurred because the representational system activated by their concurrent tasks are independent of those activated by their verbal memory task.

Furthermore, the results suggest that the mnemonic component of the monitoring tasks is unlikely to be the key factor leading to the large interference effects. The digit- and word-monitoring tasks both require working memory to keep track of which items were previously viewed and the number of occurrences of critical items. If this aspect of the monitoring tasks was the crucial factor determining the size of interference, the effect should have remained large regardless of the type of material used in the monitoring task.

Alternatively, one might suggest that the large interference effects in Experiments 1 and 2 were due to retroactive interference from the monitoring task performed prior to free recall (Underwood, 1957). A between-subject comparison of performance in the full attention experimental condition, however, argues against this interpretation. Free recall performance in the two full attention conditions is similar, even though for half of the participants it is preceded by digit monitoring and for the other half by word monitoring.

The decline in monitoring task performance in each of the DA conditions did not differ from one another, as one might have expected given the differential effects the monitoring tasks had on free recall. The mean percentage decline from single-task to DA conditions was similar for the digit- and word-monitoring tasks. Thus, whereas the size of the interference effect on memory seems to be influenced by the type of monitoring task, there is no such material specificity on monitoring task costs.

An examination of the results from the auditory CRT task shows that the overall increase in RTs in each DA condition did not differ. This suggests that the amount of resources, or the time required to monitor digits compared to words, is similar under DA conditions. The number of tones identified in the CRT task as well as the accuracy rates for the monitoring tasks are also similar. These findings argue against the possibility that a difference in resource demands or task difficulty accounts for the differential effects of the monitoring tasks on free recall.

In conclusion, this experiment shows that interference effects under DA at retrieval are influenced by the type of material used in the concurrent task. Relatively larger effects are observed when both tasks require a common verbal representational system. In the next experiment we examined whether the material-specific interference effects on memory are also observed when attention is divided during encoding.

Experiment 5

The results from Experiments 2 and 3 of the present study showed that the size of the asymmetry in interference effects from DA at encoding compared to the size at retrieval was smaller than in past studies. That is, the effect at encoding was only about 17–18% greater than that at retrieval using our word-monitoring tasks. This stands in contrast to the much larger asymmetries observed in other studies (Baddeley et al., 1984; Craik et al., 1996; Kellog et al., 1982). The results from Experiment 4 suggest that the magnitude of interference effects under DA at retrieval are influenced by the type of material used in the concurrent task.

In the next experiment we investigated whether the size of the interference effect from DA at encoding was influenced similarly by the type of material in the concurrent task. The interference effects in Experiment 3 and other studies where attention was divided at encoding (Baddeley et al., 1984; Craik et al., 1996; Kellog et al., 1982) were similar in magnitude, even though different materials were used across the studies. These results are consistent with the component-process model, which suggests that all tasks performed concurrently at encoding that are equally attention demanding should disrupt memory to a similar degree. As such, in the next experiment we hypothesized that material specificity of the task performed concurrently at encoding would not influence the magnitude of interference on memory, as it does when performed at retrieval.

In the next experiment we compared the effect of DA at encoding using the word- and digit-monitoring tasks from Experiment 4. We expected that the memory interference effect from DA at encoding would be similar in size to that found in Experiment 3 and other studies, and furthermore, that the size of the effect would not differ in the word- and digit-monitoring DA condition.

Method

Overview of Experiment

The experiment was identical to Experiment 3 except that the two-syllable monitoring task was replaced with the odd-digit monitoring task.

Participants

Participants were 24 undergraduate students at the University of Toronto who received course credit for their participation. All participants claimed to be native English speakers and to have normal or corrected-to-normal vision and hearing. The mean age of participants was 23.8 ($SD = 4.5$).

Materials and Procedure

Stimuli for the target recall tasks were the same as those used in all previous experiments. Stimuli for the word-monitoring task were the man-made word lists used in Experiments 2 and 4. Stimuli for the digit-monitoring task were the same as in Experiment 4.

Results

Target Recall Task

The magnitude of interference on free recall performance was similar in both DA conditions. There was approximately a 50% decline in recall performance when attention was divided at encoding using either the word- or digit-monitoring task. Table 9 shows the number of words recalled in each DA condition and the mean percentage decline from full to DA conditions.

The data were analyzed according to a 3 (between-subject: order of experimental condition, type of filler task in the full attention condition, and order of measurement for single-task monitoring performance) × 1 (within-subject: experimental condition) ANOVA. There were no significant main effects or interactions with the order and filler task factors on target memory task performance. There was a main effect of experimental condition, $F(2, 46) = 60.74$, $MSE = 3.40$, $p < .0001$. Planned comparisons showed that the mean number of words recalled in both the man-made and odd-digit DA conditions differed significantly from the mean in the full attention condition, $F(1, 23) = 130.79$, $MSE = 5.38$, and $F(1, 23) = 63.49$, $MSE = 8.23$, respectively, $ps < .0001$. The difference in number of words recalled between the man-made and odd-digit conditions was not significantly different, $F(1, 23) = 1.98$, $MSE = 6.80$, $p = .17$. The number of words recalled in the full attention condition did not differ depending on whether the filler task that preceded free recall was the man-made or odd-digit task, $t(23) = -0.99$, $p = .34$.

Monitoring Tasks

There was no significant reduction in either the man-made or odd-digit monitoring task performance under DA conditions with encoding. The mean accuracy rates for each

Table 9
Experiment 5: Number of Words Recalled, Percentage Decline From Full Attention in Each Condition, and Monitoring Task Accuracy Rates

Measure and condition	*M*	*SD*
Target memory task		
Words recalled		
Full attention	9.54	3.11
DA man-made	4.13	2.03
DA odd-digit	4.88	3.21
Percentage decline		
DA man-made	56	16
DA odd-digit	50	23
Monitoring tasks accuracy rates		
Baseline man-made	.72	.15
DA man-made	.67	.19
Baseline odd-digit	.71	.16
DA odd-digit	.71	.22
Filler	.74	.26

Note. DA = divided attention.

condition are presented in Table 9. The data were analyzed according to a 3 (between-subject: the two order factors and the type of filler task in the full attention condition) × 1 (within-subject: experimental condition) ANOVA. There were no significant main effects or interactions with the order and filler task factors on monitoring task performance. There was no main effect of experimental condition, $F(3, 69) = 0.27$, $MSE = 0.03$, $p = .84$.

The difference in accuracy rates between the man-made and odd-digit monitoring performance under DA conditions was not significant, $t(23) = -0.5$, $p = .61$. Moreover, the monitoring task costs (single − dual task performance for each task) did not differ, $t(23) = 0.61$, $p = .54$. Planned comparisons showed that the mean accuracy rate in both the man-made and odd-digit DA conditions did not differ from their respective single-task baselines, $F(1, 23) = 0.72$, $MSE = 0.07$, and $F(1, 23) = 0.0$, $MSE = 0.06$, respectively, $ps > .05$.

Analysis of Correlations

The correlation between the percentage decline in number of words recalled for the target memory task and the accuracy rate cost for the man-made and odd-digit monitoring task was not significant, $r = -.24$, $p = .25$, and $r = .07$, $p = .73$, respectively.

Auditory CRT

Monitoring tasks. The accuracy rate for both of the monitoring tasks suffered to a similar degree when the auditory CRT task was performed concurrently. The mean accuracy rates for the man-made and odd-digit tasks under DA conditions were .48 ($SD = .18$) and .53 ($SD = .21$), respectively. The difference between these two accuracy rates was not significant, $t(23) = -1.12$, $p = .27$. There was no effect of task order on accuracy rates for either the man-made or odd-digit monitoring tasks.

CRT tone task. The difference in number of tones correctly identified between the man-made and the odd-digit DA condition was significant, $F(1, 23) = 5.90$, $MSE = 106.80$, $p < .05$. The mean number of correct responses for each condition is presented in Table 10. There was no effect of order on number of correct responses, and the Condition × Order interaction was also nonsignificant. Planned comparisons revealed that the number of tones correctly identified in both DA conditions differed significantly from the full attention baseline condition, $F(1, 23) = 100.09$, $MSE = 192.49$, and $F(1, 23) = 86.18$, $MSE = 150.00$, respectively, $ps < .0001$.

The mean RT to identify tones is shown for correct responses only (see Table 10). As in the previous experiments, an outlier analysis eliminated RTs greater or lesser than two standard deviations from the mean for each participant in each condition. A within-subject ANOVA revealed a main effect of condition, $F(2, 46) = 21.68$, $MSE = 8{,}474.00$, $p < .0001$. There was no effect of order on RTs and the Condition × Order interaction was also nonsignificant.

Planned comparisons showed that the mean RT in both the man-made and odd-digit DA conditions differed significantly from the mean in the baseline condition, $F(1, 23) = 32.00$, $MSE = 18{,}274.81$, and $F(1, 23) = 22.48$, $MSE = 22{,}920.46$, respectively, $ps < .0001$. The difference in RT between the man-made and odd-digit DA conditions did not differ, $F(1, 23) = 0.23$, $MSE = 9{,}652.26$, $p = .64$, suggesting that the two monitoring tasks do not differ with respect to resource demands.

Table 10
Experiment 5: Number of Correct Responses and Reaction Times (in Milliseconds) for Correct Responses on the Continuous Reaction Time Task for Each Condition

	Correct response		Reaction time	
Condition	*M*	*SD*	*M*	*SD*
Baseline	105.08	28.09	771.40	206.00
DA man-made	76.75	20.93	927.50	161.31
DA odd digit	81.88	25.75	917.94	196.58

Note. DA = divided attention.

Comparison of Experiments 4 and 5

The data from Experiments 4 and 5 were re-analyzed using an ANOVA to compare the interference effects created under DA at retrieval versus encoding, with Experiment, Order of Experimental Condition, Type of Filler Task in the Full Attention Condition, and Order of Single-Task Monitoring Performance Measures as between-subject factors. A separate analysis was carried out for the percentage decline in recall performance and monitoring task costs from single-task to DA conditions.

The main effect of Experiment on percentage decline in target memory task performance was significant, $F(1, 46) = 38.93$, $MSE = 618.1$, $p < .05$. The Condition × Experiment interaction was not significant, $F(1, 46) = 1.70$. The effect of a monitoring task performed concurrently at encoding on memory task performance was significantly larger than the effect at retrieval. This pattern did not differ for the man-made and odd-digit DA conditions. Nevertheless, planned comparisons showed that interference in the man-made DA condition at retrieval was greater than that of the odd-digit DA condition, yet there was no difference in size of interference from these two DA conditions at encoding.

In the analysis of monitoring task costs, the main effect of Experiment was significant, $F(1, 46) = 10.33$, $MSE = 0.06$, $p < .05$. The Condition × Experiment interaction was not significant, $F(1, 46) = 0.47$. Monitoring task costs were significantly smaller when performed at encoding as compared to retrieval. This pattern did not differ for the man-made and odd-digit DA conditions.

Discussion

We conducted Experiment 5 to compare the size of interference, produced on free recall by DA at encoding, from monitoring tasks that consisted of either the same or different material as in the target memory task. In contrast to the pattern of effects from DA at retrieval, the word- and digit-monitoring tasks led to interference effects that were similar in size. As in Experiment 3, there was approximately a 50% decline in memory performance from full to DA conditions at encoding.

Figure 3 shows that DA at encoding is much more detrimental to memory performance than DA at retrieval. The size of the asymmetry, however, is smaller when the monitoring task involves verbal material that is similar to that in the free recall test as compared to numerical material that is different.

The results from Experiments 4 and 5 illustrate an important difference between the type of resources required by encoding and retrieval processes for a free recall task. At encoding, memory and concurrent tasks compete primarily for general resources, whereas at retrieval they compete primarily for a common representational system. Thus, any task that draws away attentional resources from the material to be encoded interferes with subsequent memory performance. However, at retrieval it appears that only those tasks that use material similar to the memory task lead to interference.

Within the framework of the component-process model, interference from DA at encoding arises from competition for strategic PFC resources, whereas interference from DA at retrieval arises from competition for common perceptual representations that are activated during recovery of the memory trace. This may explain why Baddeley et al. (1984) and Craik et al. (1996) found only small effects of DA at retrieval; the material used in their concurrent tasks was dissimilar from that in the memory task.

Consistent with the results from Experiment 3, memory encoding did not interfere with performance on either of the monitoring tasks. This stands in contrast to the much larger effect that memory retrieval had on monitoring performance (see Figure 4).

These results illustrate another difference between encod-

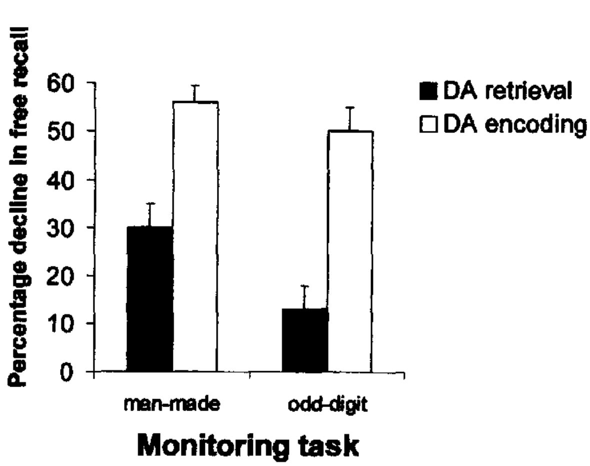

Figure 3. Mean percentage decline from full attention in free recall performance for divided attention (DA) at retrieval and encoding from Experiments 4 and 5.

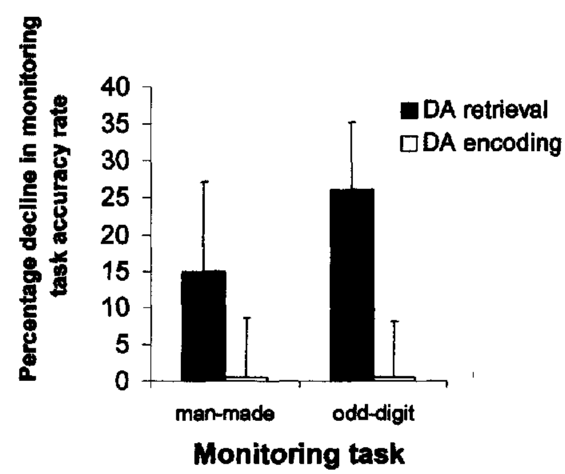

Figure 4. Mean percentage decline from single to divided attention (DA) conditions, in monitoring task performance, for Experiments 4 and 5.

ing and retrieval processes. Under DA conditions, retrieval draws more resources away from the monitoring task than encoding. One explanation for this difference, provided by Craik et al. (1996), is that encoding is a relatively more controlled process than retrieval. Allocation of attention to the encoding task under DA conditions is under the participant's control. Craik et al. examined the effect of different emphasis conditions for the memory and concurrent task under DA. They showed that a participant's performance under DA conditions at encoding is related to the amount of attention they devote to each task: Reduced attention is systematically related to reduced memory performance and a slower RT on their concurrent task.

Our results suggest that participants may not have accurately gauged the amount of attention necessary for efficient encoding and did not divert sufficient attention away from the monitoring tasks. We expect that if participants were given different emphasis instructions, as Craik et al. (1996) did, the interference effect on the memory and monitoring tasks would be related to whichever task was emphasized.

Dividing attention between a monitoring and retrieval task, however, yields a different picture. Regardless of whether memory performance was preserved or not, considerable resources were drawn away from both the word- and digit-monitoring tasks. Thus, contrary to Baddeley et al.'s (1984) claim, but consistent with Craik et al. (1996), our experiments show that retrieval cannot be considered an automatic process. It is possible that establishing and maintaining a retrieval mode is a necessary prerequisite for any memory recovery. This aspect of retrieval may be considerably resource demanding, leading to the very large monitoring task cost, regardless of whether words are successfully recovered or not.

The results from the auditory CRT task replicated those observed in Experiment 4: The level of difficulty, or amount of resources required to monitor digits compared to words, is similar under DA conditions.

General Discussion

The series of experiments on DA presented in this article suggest that free recall of words from LTM is not an automatic or obligatory process and that it is subject to interference effects under certain DA conditions. The magnitude of interference on free recall performance created under DA conditions at retrieval depends on the similarity of material in the memory and concurrent task. Under DA conditions at encoding, however, any task that draws resources away from the memory task disrupts subsequent free recall performance to a similar degree.

Using four different concurrent tasks, we found a consistently large decline in free recall when performed under DA conditions. Although each task differed with respect to its demands on STM and LTM and on semantic and phonological processing, they were all verbal and thus involved material similar to that used in the target memory task. The large interference effects observed in our study stand in contrast to other studies of verbal memory, in which the concurrent tasks were either a visual continuous RT task (Craik et al., 1996), card sorting, or digit load (Baddeley et al., 1984), which had little in common with the memory task and which led to small interference effects.

Our motivation for the study was to explore why DA had variable effects on tests of verbal memory across several studies. For this reason, we limited our study to memory for verbal material only. Although we considered only the verbal representational system, results from another group support our claim for 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. In our study, we found that digit monitoring did not lead to as much interference as did word monitoring, although the two tasks were equally difficult. These results led us to conclude, contrary to Craik et al. (1996) and Baddeley et al. (1984), that DA effects do occur at retrieval but that they are material specific.

One conclusion to be drawn from these results is that memory retrieval is no more obligatory than it is automatic. Although true, this statement does not accurately reflect what is distinctive about retrieval. Under DA at encoding, material specificity of the competing task seems to have little influence on the size of the interference effect on memory. Baddeley et al. (1984), Craik et al. (1996), and our study found similarly large effects of DA at encoding using different concurrent tasks. However, under DA at retrieval, memory performance is affected relatively little if the concurrent task does not use the same material as the memory task, as our Experiment 4 and other studies (Baddeley et al., 1984; Craik et al., 1996) have shown.

Two other findings were puzzling and require an explanation. The material-specific effect from DA at retrieval does not apply to monitoring task costs. Regardless of whether the monitoring task involved similar or different material from the target task and produced large or small interference effects, the monitoring tasks were affected equally by the memory retrieval task. The other puzzling finding is that participants could not recover their memory for the studied words, even when attention was no longer divided.

The Component-Process Model, Divided Attention, and Memory

We attempt to account for these findings within the context of the component-process model of memory. We elaborate those aspects of the model that pertain to the effects of DA on memory and, in doing so, hope to explain some of the differences between encoding and retrieval.

According to the component-process model described in the introduction, it is important to distinguish between two types of memory tests: those that rely heavily on strategic PFC resources and those that do not. The former type of memory test is presumed to have a substantial strategic component whose operation is resource demanding. On such tests of memory, DA effects are observed at retrieval as long as the concurrent task itself is resource demanding and thus draws resources away from the memory task. Examples of such tasks include recall of categorized lists (Moscovitch, 1994; Park et al., 1989), list discrimination (Dywan & Jacoby, 1990; Jacoby, 1991), and release from proactive inhibition (Moscovitch, 1989, 1994). The present experiments, however, were not concerned with such strategic tests of memory.

The problem addressed by the current experiments is whether interference at retrieval could be obtained on tests of memory, such as free recall and recognition of a list of unrelated words, for which others have not shown any effect (Baddeley et al., 1984; Craik et al., 1996). We considered whether the interference effect from DA at retrieval was dependent on the type of concurrent task. According to the model, performance on such tests is mediated primarily by MTL/H, a module whose operation is automatic and obligatory and requires few resources. The observation that under certain DA conditions, retrieval from this system can be disrupted and draw resources away from the concurrent task (Craik et al., 1996; our Experiments 1, 2, and 4), requires that the model be modified.

Retrieval Is Not Automatic

The evidence against automaticity is that there are extensive concurrent task costs when attention is divided with a memory retrieval task. Craik et al. (1996) found, however, that concurrent task costs were unrelated to success in recovering the memory trace. Put in our terms, concurrent task costs were unrelated to ecphoric processes mediated by the MTL/H. Based on this observation, Craik et al. proposed that the retrieval process that was attention demanding was the retrieval attempt or maintaining a retrieval model, which may require frontal-lobe participation.

A complementary interpretation is that establishing and maintaining a retrieval mode or monitoring the words being recalled is resource demanding, although ecphory is not.

Once in retrieval mode, ecphory itself is automatic.[6] Support for this interpretation comes from our finding of similar concurrent task costs even in those experiments where the concurrent task makes minimal demands not only on ecphory, but on STM or working memory. Indeed, in a recently completed study (Fernandes & Moscovitch, 2000), we observed concurrent task costs on an animacy and syllable-decision task for single words that were similar to those observed on the various monitoring tasks from the present study.[7]

Recent positron emission tomography (PET) studies have lent some support to this interpretation and to our model. According to our model, resource-demanding operations such as maintenance of retrieval mode should be associated with PFC activation, whereas ecphory and retrieval success should be associated with MTL/H and posterior neocortex activation. Consistent with this prediction, PET studies have shown that retrieval attempt or maintenance of retrieval mode is associated with activation of PFC, whereas the ecphoric process itself, as measured by retrieval success, is associated with activation of the MTL/H and the posterior neocortical system that together constitute the memory trace (Kapur et al., 1995; Mangels, Picton, & Craik, 1999; Nyberg, McIntosh, Houle, Nilsson, & Tulving, 1996; Schacter et al., 1996). An alternative interpretation is that PFC activation is associated with monitoring of the output from the MTL/H to verify the accuracy of the memory, determine whether it is appropriate to the goal of the task, and place it in the proper context (Rugg, Fletcher, Frith, Frackowiak, & Dolan, 1996). In either case, it is PFC, not MTL/H, that is activated and that in our view is resource demanding.

Because either maintaining a retrieval mode or monitoring the output of the MTL/H is resource demanding, concurrent task costs are observed under DA at retrieval. Moreover, these costs affect any concurrent task that itself is resource demanding. Consequently, the effects of retrieval on concurrent tasks are relatively unselective.

Is Retrieval Obligatory?

Given the unselective effects of retrieval on concurrent tasks, it is all the more surprising that the effects of concurrent tasks on memory are material specific. Indeed, our finding of a material-specific effect would seem to challenge the hypothesis derived from the component-process model that retrieval is obligatory. If retrieval (ecphory) is obligatory, once retrieval mode is established and cues are available, no concurrent task should disrupt the process. Until the present series of experiments, no study reported substantial effects from DA at retrieval on memory for a list of unrelated words.

The following is a possible explanation for the material-specific interference effects from DA at retrieval. According to the model outlined in the introduction, if either the MTL/H or neocortical component of the memory trace is disrupted, then recovery of that trace is impaired. With respect to the MTL/H, it is well known that damage to it leads to amnesia for newly acquired information. There is little information, however, about the effects on memory from damage to the neocortical representation. Our studies suggest that if the neocortical representation system is engaged in processing material similar to that which is part of the memory trace, then retrieval of that trace is impaired. Processing material that does not engage that same representational system has little effect on memory, as Experiment 4 of our study and others (Baddeley et al., 1984; Craik et al., 1996) have shown. Consistent with our interpretation, a recent PET study by Klingberg and Roland (1997) found that two concurrent tasks interfere only if overlapping parts of the cerebral cortex are activated by each.

Our finding that interference effects are relatively larger when the concurrent tasks use similar material illustrates an important feature of the retrieval process. Efficient and successful retrieval requires activation of the MTL/H, which in turn reactivates the neocortical representation of the memory trace. We believe that the latter component of retrieval is susceptible to interference from a competing task. Material-specific interference effects are unique to retrieval because, unlike the encoding process, reactivation of the neocortical representation is critical for success. At encoding, however, what is important is establishing the memory trace. Only material that is consciously apprehended can be encoded by the MTL/H. Thus, formation of a memory trace can be disrupted by any concurrent task that draws attention away from the information to be encoded.

Why Are Words From the Memory Task Never Recovered?

What remains to be explained is why additional memories cannot be retrieved, even when the concurrent task at retrieval has terminated. It is possible that concurrent activation of the neocortical representation, by a material-specific concurrent task, corrupts the memory trace. One way this can occur is by disrupting short-term consolidation or cohesion of the recently acquired memory (Moscovitch, 1995; Nadel & Moscovitch, 1997). Alternatively, the DA

[6] The idea that establishing a retrieval mode is a prerequisite for recovering episodic memories is an essential aspect of Tulving's (1983) theory of episodic memory. It helps account for the common observation that our perceptions and thoughts do not usually act as cues to recover episodic memories, but rather to form the basis of our current representation of the environment, our impressions of it, and of our expectations. Once in retrieval mode, however, the very same percepts and thoughts act as retrieval cues. For example, when in retrieval mode, one does not attend per se to the person with whom one is conversing, or to the conversation itself, but rather to what the person and conversation remind one of. Although entering retrieval mode occurs voluntarily, a cue may be so salient that it triggers ecphory directly and a memory is recovered unintentionally.

[7] An alternative interpretation is that one cannot separate the conscious apprehension of the cue initiating the ecphoric process and the apprehension of its product from the ecphoric process itself. It may be that the attentional bottleneck is at apprehension but that the ecphory itself also is resource demanding. Our experiments cannot distinguish between this interpretation and the one we offered, which we believe is the more parsimonious of the two.

condition at retrieval may have weakened or suppressed the memory trace making it inaccessible, and further cuing is necessary to elicit the memory.

Whether either of these interpretations is correct remains to be confirmed. If the consolidation process were truly disrupted, we would not expect participants to remember additional words, even on a recognition test that provides more external cuing and retrieval support (Craik, 1983). If, however, interference from DA serves only to make memories inaccessible, they should be recovered when a recognition test is used to probe for additional memories. We are currently investigating these possibilities.

Conclusions

By focusing on the various component processes required for encoding and retrieval, we have been able to account for the asymmetric effects of DA on memory. DA at encoding leads to a relatively larger interference effect than DA at retrieval, and the magnitude of that effect does not depend on the material specificity of the concurrent task. At encoding, formation of the memory trace requires conscious apprehension of the material. Any concurrent task that diverts resources necessary for conscious apprehension of that material prevents it from being encoded and becoming part of a memory trace, leading to very poor memory.

On the other hand, DA at retrieval leads to relatively smaller interference effects than DA at encoding, but the size of the effect depends on the material specificity of the concurrent task. Retrieval requires at least two component processes: (a) establishing and maintaining the retrieval mode, which is mediated by the PFC, and (b) reactivating the memory trace by its interaction with the cue (ecphory). The memory trace consists of an ensemble of neurons from the MTL/H and posterior neocortical representational systems. Establishing and maintaining retrieval mode, or monitoring output, is resource demanding and is reflected in large concurrent task costs regardless of material. Because ecphory is automatic and obligatory, 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. Thus at retrieval, concurrent task costs are unselective, but memory costs are material specific.

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