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The Effects of Divided Attention on Encoding and Retrieval Processes in Human Memory

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The authors examined the effects of divided attention (DA) at encoding and retrieval in free recall, cued recall, and recognition memory in 4 experiments. Lists of words or word pairs were presented auditorily and recalled orally; the secondary task was a visual continuous reaction-time (RT) task with manual responses. At encoding, DA was associated with large reductions in memory performance, but small increases in RT; trade-offs between memory and RT were under conscious control. In contrast, DA at retrieval resulted in small or no reductions in memory, but in comparatively larger increases in RT, especially in free recall. Memory performance was sensitive to changes in task emphasis at encoding but not at retrieval. The results are discussed in terms of controlled and automatic processes and speculatively linked to underlying neuropsychological mechanisms.

The main purpose of this article is to examine the similarities and differences between encoding and retrieval processes in human memory. At first it seems that the two sets of processes are very similar. This position follows from Tulving's encoding specificity principle, Kolers's views on repetition of operations, and the concept of transfer-appropriate processing. In the same vein, Craik (1983) has suggested that encoding processes are essentially those involved in the perception and comprehension of events, and that retrieval processes represent an attempt to recapitulate these initial processes. In addition, evidence from neuropsychology and neuroscience suggests that the pathways involved in retrieval overlap substantially with those involved in perception and storage of the same type of information.

If encoding and retrieval processes are indeed similar, experimental manipulations that affect one set of processes should have a similar effect on the other set. However, one apparent exception to this proposition comes from studies of divided attention (DA). Baddeley, Lewis, Eldridge, and Thomson (1984) confirmed previous findings that the performance of a concurrent task during encoding reduced later memory performance, but they also found that dividing attention in the same way during retrieval had virtually no effect on memory performance. This surprising result suggests that retrieval processes are substantially automatic. Unlike encoding processes that place a heavy demand on attentional resources, it appears from Baddeley et al.'s findings that retrieval can proceed without such resources.

Four experiments were conducted to explore these issues. Lists of words or word pairs were studied and retrieved either under full attention or while participants carried out a concurrent continuous reaction-time (CRT) task. When attention was divided at encoding, memory performance dropped substantially, but concurrent reaction time (RT) was slowed by a relatively small amount. In contrast, DA at retrieval resulted in comparatively slight drops in memory (none in the case of recognition) but a large increase in concurrent RT in the case of free recall, with systematically smaller increases in RT associated with cued recall and recognition. Thus (largely confirming the findings of Baddeley et al., 1984), DA at retrieval has little or no effect on memory performance, but the present results show that retrieval is not "automatic" in any simple sense—concurrent task costs are heavier than they are at encoding. These costs do not seem to reflect postretrieval editing or response selection, because we also found no relation between RT values and the number of words retrieved in any 5-s interval. Instead, we propose that RT costs are associated with a "retrieval mode" state; independent evidence for this state comes from recent PET studies.

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Two other sets of findings are, first, that instructions to emphasize either the memory task or the RT task had a large effect on memory during encoding, but none during retrieval. Again this result points to the consciously controlled nature of encoding processes and the relatively automatic nature of retrieval. Second, by means of a calibration procedure we examined whether memory performance under DA conditions was predicted by the amount of slowing on the concurrent RT task. A similar pattern of results in all four experiments showed that DA at encoding yielded recall values lower than predicted, whereas DA at retrieval yielded values somewhat higher than predicted values.

The experiments thus revealed a number of differences between encoding and retrieval. How are these differences to be reconciled with the similarities listed previously? One possibility is that the final mental (and cortical) representations of events are very similar at encoding and retrieval, but that the control processes involved in laying down and reactivating the representations are substantially different. The concluding discussion raises questions for future work on memory that should lead to greater integration among the areas of neuropsychology, neuroscience, and cognition.

The Effects of Divided Attention at Encoding and Retrieval

How similar are encoding and retrieval processes in human memory? Most memory researchers would agree that a strong degree of similarity is necessary for effective remembering. One set of ideas was proposed by Tulving (1983; Tulving & Thomson, 1973) as the encoding specificity principle, which states that items are encoded in a highly specific way, and effective retrieval cues must reflect that specificity. The notion of a necessary overlap between encoding and retrieval processes is also captured by the idea of transfer-appropriate processing (Bransford, Franks, Morris, & Stein, 1979; Morris, Bransford, & Franks, 1977; Roediger, Weldon, & Challis, 1989). Another influential set of ideas was proposed by Kolers (1973, 1979; Kolers & Roediger, 1984) under the general heading of a proceduralist view of mind. In Kolers's view, "recognition is achieved by virtue of the correlation between the operations carried out on two encounters with a stimulus event. The more similar the operations, the readier the recognition" (Kolers, 1979, p. 383). Finally, within the context of the levels-of-processing framework, Craik and Lockhart (1972) suggested that encoding operations are simply those processes whose primary functions are perception and comprehension of incoming stimuli, and Craik (1983) proposed that "just as encoding processes vary in depth, elaboration, extensiveness and precision, retrieval processes may vary in similar ways. Encoding and retrieval processes may be qualitatively similar, or even identical, despite the fact that they are carried out with different goals in mind" (Craik, 1983, p. 354). In addition, researchers in the fields of neuropsychology and neuroscience have suggested that the neural pathways involved in perceptual processing of stimuli also participate in their storage and recovery (Mishkin & Appenzeller, 1987; Moscovitch, 1992; Squire, 1992; Squire, Cohen, & Nadel, 1984). It is at least arguable then that memory encoding processes consist essentially of operations whose primary functions are to perceive and understand external events, and that memory retrieval processes reflect efforts to reinstate the same pattern of mental and neural operations that existed at the time of the initial experience.

On the other hand, a number of results indicate basic differences between the two sets of processes. For example, there is evidence that depressive drugs have a detrimental effect on the encoding of new information, but little if any effect on retrieval of material already learned (Birnbaum & Parker, 1977; Birnbaum, Parker, Hartley, & Noble, 1978; Curran, 1991). The similarity between encoding and retrieval is also challenged by findings from the dual-task paradigm, in which participants perform a second activity while simultaneously encoding or retrieving information in a memory task. When attention is divided between the secondary task and the encoding phase of the memory task, the results are unequivocal; memory performance declines relative to conditions of full attention, and it declines systematically as the secondary task increases in complexity (Anderson & Craik, 1974; Baddeley et al., 1984; Murdock, 1965). In his study using card sorting as the secondary task, Murdock (1965) also found that free-recall performance was higher when memory was emphasized at study, relative to a condition in which speed of card sorting was emphasized. Taken together, these results suggest that memory encoding processes require attention, that there is a trade-off in this respect between memory and the concurrent task, and that allocation of attention to encoding processes is to some extent under the participant's control.

The effects of division of attention at retrieval are less clear-cut, however. One set of studies measured performance on a visual tracking task carried out concurrently with either the learning phase or the recall phase of a verbal memory task (Johnston, Greenberg, Fisher, & Martin, 1970; Martin, 1970; Trumbo & Milone, 1971). All three studies found that tracking performance was impaired by both encoding and retrieval; in fact, recall was more attention demanding than learning, as measured by errors on the tracking task. Similarly, using a technique in which participants responded to auditory digit targets presented concurrently with the learning and recall phases of a visually presented verbal memory task, Griffith (1976) found that recall was attentionally demanding. Griffith's study also showed that "expended processing capacity" (as measured by RT to the auditory stimuli) was greater during recall than during the encoding phase. Other experiments using concurrent RTs to single target stimuli have yielded the same pattern of results. For example, in a short-term memory probe task, Johnston, Griffith, and Wagstaff (1972) found RTs of 312, 440, and 531 ms for baseline, presentation, and recall phases, respectively, and Griffith and Johnston (1973) reported RTs of 364 and 397 ms during the list presentation and test phases, respectively, of a paired-associate task. All of these experiments thus agree that "retrieval consumes more processing capacity than does encoding of information" (Johnston et al., 1972, p. 516).

Other research using the dual-task paradigm has focused on the memory task rather than on the secondary task. If retrieval is especially resource demanding, it would be expected that performance on the memory task would be particularly vulnerable to dual-task interference during the retrieval phase, yet Baddeley et al. (1984) found either no reduction or only a slight reduction in episodic memory accuracy when attention was divided at retrieval in six experiments involving free recall, paired-associate learning, and recognition. These authors did find an effect of DA on recognition latency, and on latency of retrieval from semantic memory, but little or no effect on retrieval accuracy. On the basis of these findings, Baddeley et al. concluded that retrieval processes may be largely automatic, in contrast to encoding processes, which showed consistently large decrements under DA conditions. With respect to the apparent discrepancy between their results and the results of studies showing that retrieval has a marked effect on a concurrent tracking task (e.g., Martin, 1970; Trumbo & Milone, 1971), Baddeley et al. suggested that the process of accessing the memory trace places relatively light demands on attention, but that response selection takes time, and this time resource is also drawn on by the secondary task.

The literature thus yields the apparent paradox that retrieval processes are very attention demanding, as indexed by the slowing of performance on a concurrent task, and yet are themselves relatively immune to disruption (although they are slowed) by a concurrent task. This immunity is not shared by encoding processes. When attention is divided at encoding, memory performance is markedly reduced, and performance on the concurrent task is also reduced (Anderson & Craik, 1974), although perhaps not so much as it is reduced by concurrent retrieval (e.g., Johnston et al., 1970; Johnston et al., 1972; Martin, 1970). One theoretical implication of these differences between encoding and retrieval processes is the doubt they cast on the suggestion (Craik, 1983; Kolers, 1973) that encoding and retrieval processes may be qualitatively similar, or even identical; demonstrated qualitative differences between encoding and retrieval force a reevaluation of this suggestion.

Many of the studies just reviewed suffer from methodological shortcomings that should be corrected before reassessing the relevant theoretical positions. Typically, studies have focused largely either on memory performance (e.g., Baddeley et al., 1984; Murdock, 1965) or on concurrent task performance (e.g., Johnston et al., 1970). When the focus is on memory, the precise attentional demands of the secondary task are often not measured. For example, concurrent card sorting leaves indeterminate amounts of time and attention to carry out some memory-related processes, and the same may be said for holding a string of digits in mind (Baddeley et al., 1984) or for the detection of occasional targets (e.g., Griffith, 1976; Macht & Buschke, 1983). Some concurrent tasks, like card sorting, clearly embody some relatively mechanical motor components, and it is possible that participants could use this "motor time" to carry out more central processing operations in the memory task. These objections do not hold for the continuous tracking task used by Johnston et al. (1970) and by Trumbo and Milone (1971), but these investigators examined memory tasks that did not tap secondary memory processes, which are the main focus of this article. Further shortcomings of previous studies include difficulty ascertaining how participants allocate their attention between the two tasks; trade-offs in performance as a function of different emphasis on one task or another are typically not measured. The measurement of trade-offs also requires some common metric by which performance on the two tasks may be assessed, and such common units have not usually been discussed.

The basic purpose of the present series of experiments was to assess the similarities and differences between encoding and retrieval processes in human memory. Specifically, we wished to look again at the attentional costs of memory encoding and retrieval in a dual-task paradigm embodying the following features. First, we used well-understood memory paradigms in which encoding and retrieval phases could be clearly separated; the tasks were free recall, paired-associate recall, and recognition memory. To avoid modality-specific interference, we presented the word lists auditorily and asked for spoken responses at retrieval, whereas the concurrent task used visual stimuli and manual responses. This concurrent task was a continuous four-choice RT task, in which the participant's correct response immediately caused the next stimulus to appear. Because performance did not reach ceiling on either task performed singly, we argue that each task required full attention to be performed by itself. When performed together, the tasks allowed for assessment of performance throughout the dual-task interval. We were able to estimate the mechanical motor aspects of the RT task by carrying out several trials in which participants simply pressed the keys systematically in the absence of stimuli. Finally, we attempted to provide a common metric for the memory and RT tasks in terms of time used. This measure is obvious in the case of the RT task; in the memory tasks, we first "calibrated" encoding and retrieval performance against time in a manner described later.

We expected that division of attention at encoding would result in substantial decrements in later memory performance and that this would be true for free recall, cued recall (i.e., paired associates), and recognition. We also expected that dual-task conditions at encoding would slow performance of the four-choice RT task relative to performance of the RT task alone. With respect to retrieval, the predictions were less certain. If Baddeley et al. (1984) are right and retrieval processes are automatic, then the addition of the RT task during retrieval should have little effect on either memory performance or the RT task itself. On the other hand, if retrieval processes behave like encoding processes, dual-task performance should be associated with a reduction in memory and an increase in RT.

In the latter case, it could be predicted that the "DA costs" (i.e., the slowing of RT) would be greatest for retrieval under free-recall conditions, less for cued recall, and least for recognition. This prediction follows from the notion that memory retrieval tasks vary in the attentional resources required to carry them out. Craik (1983) suggested that some tasks (e.g., recognition) are well supported by the external context (in this case, re-presentation of the items to be recognized) and so require relatively few resources. In other tasks, such as free recall, the external environment offers relatively little support, and so the retrieval processes must be "self-initiated" in an effortful manner that requires substantial resources. Craik speculated that free recall requires more self-initiated processing than does cued recall, but that cued recall requires more than does recognition. On the assumption that slowing of the RT task reflects the attentional demands of a concurrent memory retrieval task, it follows that free recall should be associated with the greatest RT slowing, and recognition with the least. In fact, Craik and McDowd (1987) showed that dual-task RT costs were greater for cued recall than for recognition.

The experiments reported herein had two other features that require some explanation. First, the dual-task portions of Experiments 2, 3, and 4 were run under three different emphasis conditions; participants were instructed either to concentrate primarily on their memory performance, RT performance, or to share their attention equally between the two tasks. If encoding and retrieval processes are under conscious control, this manipulation should result in a trade-off between tasks. If, on the other hand, retrieval processes are automatic, differences in emphasis should have little effect on either task. The second feature relates to our examination of time as a resource. In Experiments 1, 3, and 4, we included a series of single-task conditions (memory only) to establish the relations between the time available for encoding or retrieval processes and memory performance. In Experiment 1, for example, we presented word lists at the rate of 0.75, 1.5, 2.5, and 4.0 s/word, and so generated a function relating encoding time to later recall performance. If memory performance under dual-task conditions is also a function of the time available for encoding processes, it should be possible to predict recall from the amount by which the RT task slows from single-task to dual-task conditions. As an example, if average single-task RT is 400 ms and dual-task RT is 600 ms, then (assuming no parallel processing) we suppose that 200 ms is available for memory encoding. During the 60-s encoding interval, there would therefore be 100 RT key presses (60 s/600 ms) and therefore a total of 20 s (200 ms × 100) available for encoding. Given a 15-word list, the implication of the present analysis is that each word has 20/15 = 1.3 s functionally available for encoding purposes. The final step is to examine whether a value of 1.3 s entered into the previously generated presentation rate/recall function yields a recall value equivalent to the recall value found under dual-task conditions. These manipulations thus enabled us to ask whether memory performance can be predicted on the basis of time available, whether the assumption of no parallel processing between the memory and RT tasks is a reasonable one, and whether encoding and retrieval processes behave similarly with respect to the trade-off between the two tasks.

Experiment 1

The main goal of the first experiment was to measure the attentional costs of encoding and retrieval in the free recall paradigm. The continuous RT task was performed alone and concurrently with encoding, recall, or both encoding and recall phases of the memory task; attentional costs were indexed by the increase in RT from single- to dual-task performance. Free recall was also measured under single-task conditions, so the effects on memory of division of attention at encoding and retrieval could be assessed. A second, equally important, purpose of Experiment 1 was to test the hypothesis that any observed reduction in memory performance at encoding or retrieval is attributable to a trade-off of processing resources between memory and the concurrent RT task. We addressed this problem by specifying time as the common resource used by the tasks and their components. The expression of RT task performance in terms of time used is straightforward; performance is measured in terms of RT per response, and comparison of these times during single- and dual-task processing gives a measure of the resources consumed by the primary task or by the need to manage two simultaneous tasks. Converting memory performance into units of time must be done by a calibration function. It is well established that recall increases as a function of encoding time per item (Cooper & Pantle, 1967; Murdock, 1974; Roberts, 1972), so in Experiment 1 we first constructed a function relating presentation time at encoding to free recall, and then used this calibration function as a method of converting recall levels to time used. Further details of the method and results are provided in a later section on trade-offs between memory and RT.

Method

Participants. The participants were 32 University of Toronto undergraduates, who took part in the experiment for course credit.

Stimuli. The words used in the memory task were two-syllable common concrete nouns, allocated randomly into 7 experimental lists of 15 words each. Two formats of the experiment were prepared, with half of the participants performing Format A and half Format B. The formats differed in that the tasks were presented in a different order and contained different sets of 105 words. In addition, within each format, half of the participants performed the tasks in one order and the remaining participants performed the tasks in the reverse order.

Experimental tasks. The memory task consisted of the auditory presentation of one of the 15-word lists at a rate of 4 s/word, followed immediately by an arithmetic task, the purpose of which was to eliminate recency. In the arithmetic task, participants heard a sequence of 20 random digits (1–9) presented auditorily at a 1-s rate; the participants' task was to add 3 to each number and respond orally. This task was immediately followed by the memory retrieval phase, in which participants attempted to recall the 15 words in any order. The retrieval phase lasted 30 s, and participants recalled orally; their spoken responses were tape recorded for later transcription. In overview, the memory task was free recall, with a 60-s encoding phase (15 words × 4 s), an interpolated arithmetic task, and a 30-s recall phase.

During the recall phase, the computer recorded beeps on the participants' response tape at 2.5, 5, 10, 15, 20, 25, and 30 s, to analyze temporal response patterns. In addition to the lists presented or recalled under DA conditions, further 15-word lists were presented auditorily at rates of 0.75, 1.5, 2.5, or 4.0 s/word for the purpose of constructing the calibration curve. These lists were presented under full attention conditions at both encoding and retrieval.

The RT task involved a visual display on a computer screen and manual responses on the computer keyboard. The display consisted of four boxes, arranged horizontally. An asterisk appeared at random in one of the boxes, and the task was to press the corresponding key (Z, X, . , or /) on the keyboard. A correct response caused the asterisk to move immediately to one of the other three boxes at random; the asterisk did not move until the correct key was pressed, and it never appeared in the same box on successive RT trials. The goal was to carry out the task as quickly and accurately as possible. The task was thus a CRT task; it was performed either for 60 s (during the encoding phase) or 30 s (during the retrieval phase). Because the target asterisk did not move until the correct key was pressed, no errors were recorded; instead, the RT for that trial would be longer than average, and the level of performance was measured solely by mean RT. Participants' responses were recorded by the computer, which then printed out the number of correct responses and the average RT for that 30-s or 60-s trial.

The CRT task was performed either alone for 60 s, concurrently with the encoding phase of the memory task (60 s), concurrently with the retrieval phase of the memory task (30 s), or at both encoding and retrieval. In addition, two further tasks were carried out as controls. The first was a "press rate" task included to estimate the motor component of the CRT task with no choice involved. Participants were presented with the same four-box visual display as in the CRT task, but in this case the asterisk was displayed continuously for 5 s in each box sequentially from left to right. Participants pressed the key corresponding to the box with the asterisk as often and as rapidly as possible during the 5-s interval, and then pressed the next key with the next finger as often and as rapidly as possible until all four boxes had been displayed for a total of 20 s. Finally, 21 participants performed a "response conflict" task designed to assess the amount of RT slowing attributable to simply making a verbal response in the absence of any need to retrieve the response. Participants performed the CRT task normally for 30 s, but in this task the computer was programmed to beep at intervals corresponding to the average pattern of retrieval responses during a DA recall trial. In this experiment, 8.2 words were recalled on average, so in the response conflict task the tone sounded 8 or 9 times, with more beeps occurring at the beginning of the 30-s interval (to mimic the typical temporal pattern of recall). The participants' task was to concentrate on performing the CRT task, but also to say the same preassigned two-syllable noun (e.g., "market") each time the tone sounded. Because of a procedural oversight, only 21 of the 32 participants performed this task.

Procedure and design. We used a within-subjects design with all participants performing all tasks, although in two different orders and with two different sets of materials. Participants were first given a description of the tasks, followed by practice trials on the CRT task alone, the arithmetic task, the free-recall task alone, and the free-recall task with the CRT task at both encoding and retrieval. Participants were also given practice at the press rate and response conflict tasks. During the main part of the experiment the following CRT tasks were presented: CRT task alone for 60 s (presented twice); press rate task for 20 s (presented twice); and response conflict task for 30 s (presented three times). The following memory tasks were presented: memory task alone at 0.75, 1.5, 2.5-s rates; free encoding and free retrieval (free–free) at a 4-s rate; CRT at encoding and free retrieval (DA–free) at a 4-s rate; free encoding and CRT at retrieval (free–DA) at a 4-s rate; and CRT at encoding and retrieval (DA–DA) at a 4-s rate.

The memory tasks were each given once; thus there were seven experimental memory trials. To construct Format A, the various memory and CRT tasks were ordered randomly, but with the provision that the CRT tasks occurred in both halves of the order. Format B was simply a different random ordering of the same tasks, but with a completely different set of words in the memory tasks. In order to emphasize the division-of-attention aspects, participants were informed that the CRT task was the primary task and that in dual-task conditions they were to assign priority to it while also doing as well as they could on the memory task.

Results

Single-task performance. Mean values for the RT tasks are shown in the top section of Table 1. The average latency for repeated presses of the response keys when no decision was involved (press rate) was 182 ms, compared with an average response latency of 420 ms in the CRT task. On the assumption that press rate measures the motor component of overall reaction time, we can therefore conclude that motor time represents 43% of the total response latency. The mean RT in the response conflict task (413 ms) was nonsignificantly higher, $t(20) = 1.28$, $p > .05$, than the mean RT in the CRT task alone (409 ms for the 21 participants who performed the response conflict task), showing that simple output conflicts are not the reason for the slowing of CRT responses under DA conditions during the retrieval phase.

Table 1
Mean RT and Free-Recall Scores for the Different Tasks in Experiment 1

	RT (ms)		Recall (words)	
Experimental task	*M*	*SD*	*M*	*SD*
RT tasks				
Press rate	182	18		
CRT task alone	420	43		
Response conflict task	413	44		
Calibration tasks				
Free–free (0.75 s)			2.91	1.77
Free–free (1.50 s)			5.38	2.85
Free–free (2.50 s)			7.53	2.82
Free–free (4.00 s)[a]			9.44	2.61
Dual-task conditions				
Free–free (4 s)[a]	420	43	9.44	2.61
DA–free (4 s)	462	75	5.09	2.13
Free–DA (4 s)	566	134	8.22	2.72
DA–DA (4 s)[b]				
Encoding	446	57	4.91	2.56
Retrieval	535	125		

Note. RT = reaction time; CRT = continuous reaction time; DA = divided attention.
[a] The free–free (4-s) data are presented twice. [b] In the DA–DA condition, RT was measured both at encoding (60 s) and at retrieval (30 s).

The middle section of Table 1 shows the mean free-recall scores as a function of the four presentation rates. These data are discussed in a later section.

Dual-task performance. The bottom section of Table 1 shows RT and recall values in the DA conditions. The free–free condition is the same as the 4-s condition shown under Calibration tasks. The data show that, in line with previous studies, DA at encoding reduces recall substantially (5.09 compared with 9.44 words, $t[31] = 13.21$, $p < .001$), but (relative to retrieval) that DA has a small but reliable effect on the CRT task (462 ms compared with 420 ms, $t[31] = 4.34$, $p < .001$). Conversely, DA at retrieval is associated with a smaller reduction in recall (8.22 compared with 9.44 words, $t[31] = 3.77$, $p < .001$), but with a larger increase in RT (566 ms compared with 420 ms, $t[31] = 7.28$, $p < .001$). In addition, both memory performance, $t(31) = 9.16$, $p < .001$, and CRT performance, $t(31) = 6.73$, $p < .001$, differed reliably between DA at encoding and DA at retrieval. When attention was divided at both encoding and retrieval (DA–DA), recall performance was more or less at the levels found for DA–free; this recall level was significantly lower than the free–free level, 4.91 compared with 9.44, $t(31) = 10.35$, $p < .001$, but not significantly different from the DA–free level, 4.91 versus 5.09, $t(31) = 0.48$, *ns*. The RT values in the DA–DA condition also echoed the values found in the corresponding phases of the other conditions. That is, whereas the mean CRT value for the encoding phase differed reliably from the CRT-alone value, 446 versus 420 ms, $t(31) = 4.34$, $p < .001$, the difference of 26 ms was much less than the difference of 115 ms found at retrieval, 535 versus 420 ms, $t(31) = 6.29$, $p < .001$.

Trade-offs between tasks. The data from the calibration task (Table 1) and their use in assessing trade-offs between the memory and RT tasks are analyzed and discussed, along with comparable data from Experiments 3 and 4, in a later section.

Discussion

The experiment yielded a number of interesting results. First, Table 1 shows that (relative to the single-task free–free condition) DA at encoding led to a marked reduction in recall, but that response latencies on the CRT task showed a small but significant increase. On the other hand, DA at retrieval was associated with a relatively slight (though reliable) drop in recall level, but with a marked rise (150 ms) in RT. In addition, the present experiment found that DA at both encoding and retrieval resulted in a recall pattern similar to DA at encoding, but with RT levels echoing the corresponding levels of the DA–free and free–DA conditions. The present results thus confirm that DA at encoding is much more disruptive to recall performance than is DA at retrieval, although (unlike Baddeley et al., 1984, but like Park, Smith, Dudley, & Lafronza, 1989) we do find a reliable drop in recall when attention is divided at retrieval.

However, we also found in Experiment 1 that performance on the CRT task was much more affected by DA at retrieval than by DA during encoding. It therefore cannot be maintained that retrieval is automatic or cost free in terms of processing resources. Apparently, recall levels are relatively well protected, but at some considerable cost to performance on other concurrent tasks (in line with previously reported results; e.g., Griffith, 1976; Johnston et al., 1970; Martin, 1970; Trumbo & Milone, 1971). One possibility is that recall is somehow obligatory or autonomous; that is, it is automatic in the sense that items are retrieved without much conscious control. But it is clear that retrieval is not cost free; on the contrary, the obligatory recall process appears to draw rather heavily on processing resources.

If this high-cost aspect of the retrieval process is concerned with the evaluation of retrieved items for their validity in terms of current search criteria (e.g., editing and response selection before commitment to an overt response), then it seems likely that processing costs would rise as a function of the number of items retrieved in a given time frame. Table 2 shows the mean RT values within 5-s recall intervals as a function of the numbers of words recalled in that interval. Data are provided for the two conditions that involved DA at retrieval, free–DA and DA–DA. For this table, we excluded cases in which participants gave 5-s RT values that exceeded 2.5 standard deviations above the mean RT for that condition. Thus, for free–DA we excluded the ten cases in which RT exceeded 1180 ms, and for DA–DA we excluded the three cases in which RT exceeded 1890 ms. In addition, we distinguished two types of interval in which no words were recalled: intervals within a participant's successful recall range and intervals after he or she had finished recalling. We thought that if participants felt they could recall no further words, they might devote more attention to the CRT task and thus reduce RT levels; these final intervals are designated "0(tail)" in Table 2. In fact, the table shows no systematic trend for RT to increase as recall increased.[1] The costs associated with retrieval appear to be independent of the number of words actually retrieved; they are therefore not likely associated with editing, evaluation, or response selection. On the other hand, the four cases of zero recall shown in Table 2 are all substantially above the RT baseline value of 420 ms. Therefore, the RT costs may be associated with the attempt to retrieve (or "retrieval mode," Tulving, 1983), regardless of the success of the retrieval attempt.

Experiment 1 shed light on one further aspect of division of attention at recall—the possibility that performance on a concurrent task is slowed because of response conflicts

[1] As one might expect, both the average RT and the numbers of words recalled decline from the first to the sixth output interval (0.70 to 0.53 s and 2.44 to 0.50 words, respectively, in the case of free–DA, and 0.81 to 0.49 s and 1.94 to 0.09 words, respectively, in the case of DA–DA). However, the mean partial correlation between RT and words recalled (partialing out output interval) was $r = +0.20$ in the case of free–DA and $r = +0.13$ in the case of DA–DA. Neither correlation is significantly greater than zero, confirming the conclusion that RT is not significantly related to the amount recalled.

Table 2
Mean RT Values (in Seconds) at Retrieval as a Function of Number of Words Recalled per 5-s Interval (Experiment 1)

Experimental condition	Number of words recalled					
	0	1	2	3	4+	0(tail)
Free–DA						
RT	0.52	0.61	0.58	0.55	0.53	0.48
n	44	40	31	28	12	27
DA–DA						
RT	0.51	0.55	0.67	0.54	0.49	0.53
n	51	37	23	17	5	55

Note. 0(tail) refers to intervals at the end of the recall period in which participants recalled no words (see text). *n* refers to the number of cases in each condition. Free–DA denotes divided attention at retrieval only; DA–DA denotes divided attention at both encoding and retrieval. RT = reaction time; DA = divided attention.

between the concurrent task and recall. We had hoped to minimize such conflicts by having participants recall orally and by using manual responses for the CRT task, but it might still be the case that the mechanical processes involved in verbal articulation (as opposed to the processes of retrieval per se) interfered with performance of the CRT task. This possibility is ruled out, however, by the finding that participants could respond as rapidly in the response conflict task (in which they spoke a predesignated word in response to an auditory cue) as in the CRT task alone condition. This result is in line with McLeod and Posner's (1984) finding that shadowing a spoken message does not require attention.

Experiment 2

The purpose of the second experiment was to obtain further information on the characteristics of encoding and retrieval processes by again using the DA tasks from Experiment 1. In this case we had participants perform the two tasks simultaneously under three different conditions of emphasis. In all three conditions participants performed both tasks to the best of their ability, but in one condition participants were told to emphasize memory performance, in a second condition they were told that both tasks were equally important, and in the third condition they were told to emphasize performance of the CRT task. If it is the case that memory retrieval processes are substantially autonomous, whereas encoding processes are more reliant on attentional control and are therefore disrupted when attention is divided, recall performance should be less affected by the emphasis manipulation in DA at retrieval than in DA at encoding.

Method

Participants. Thirty-two undergraduate students from the University of Toronto participated in the experiment for course credit or for payment.

Stimuli. The words used in the memory task were 210 two-syllable common concrete nouns, allocated randomly into 14 lists of 15 words each. The lists were recorded on an audiotape recorder at the rate of 4 s/word. All participants heard the 14 lists in the same order, but 8 different task presentation formats were used (as described later) so that groups of 4 participants received identical combinations of words and experimental conditions.

Experimental tasks. The memory task and the CRT task were essentially those used in Experiment 1. The memory task thus consisted of the auditory presentation of 15 words, followed by a 20-s arithmetic task to eliminate recency, and finally by a 30-s free-recall interval in which the participant made oral responses, which were tape recorded for later analysis.

Procedure and design. In this experiment there was no DA–DA condition; that is, attention was divided either at encoding or at retrieval, but not at both. Also, we did not include conditions in which word lists were presented at different rates; in this experiment, a 4-s presentation rate was used throughout. In all cases participants performed the CRT task alone for 30 s three times and for 60 s three times. The memory task was also performed alone (i.e., under full attention conditions) for two trials, and the two tasks were performed simultaneously (i.e., DA conditions) for a total of 12 trials. Before each DA trial, the participant was informed whether the CRT task would be performed during the encoding phase or during the retrieval phase. Additionally, participants were instructed before each trial to concentrate primarily on the memory task (while continuing to perform the CRT task as well as possible), to concentrate primarily on the CRT task (while continuing to encode or retrieve the memory list as well as possible), or to weight each task equally. For convenience, these different emphasis instructions are referred to as "memory," "RT," and "50/50," respectively, although it should be borne in mind that participants always performed both tasks in the DA conditions. The 12 DA trials were thus made up of two replications of the 3 × 2 combinations of memory, RT, and 50/50 with DA at encoding or at retrieval.

Participants were first given a description of the tasks in the experiment, followed by practice on each task. First, they practiced the CRT task for two trials of 30 s each, and then the interpolated arithmetic task for two trials. A version of the memory task was then given; 10 one-syllable words were presented auditorily at a rate of 3 s/word, followed by the arithmetic task and then by spoken recall for 30 s. Finally, a further memory trial was conducted as in the previous trial except that the CRT task was also performed at both encoding and retrieval.

After these practice trials, the experimental trials were presented. In all, eight formats were used; the four major conditions (memory, RT, 50/50, and the memory task alone, free–free) were presented in an order governed by a Latin square design, yielding 24 different orders. In addition, half of the participants performed the DA-at-encoding version of each condition followed by the corresponding DA-at-retrieval version, and the other half performed the conditions in the order DA at encoding followed by DA at retrieval. Each experimental condition was performed once, followed by a 5-min break; then the conditions were repeated in the reverse order.

Results

Figures 1A and 1B show the results from the memory task and the CRT task, respectively. Participants recalled 8.7 words on average in the free-encoding/free-retrieval condition. The recall level dropped by approximately one item in

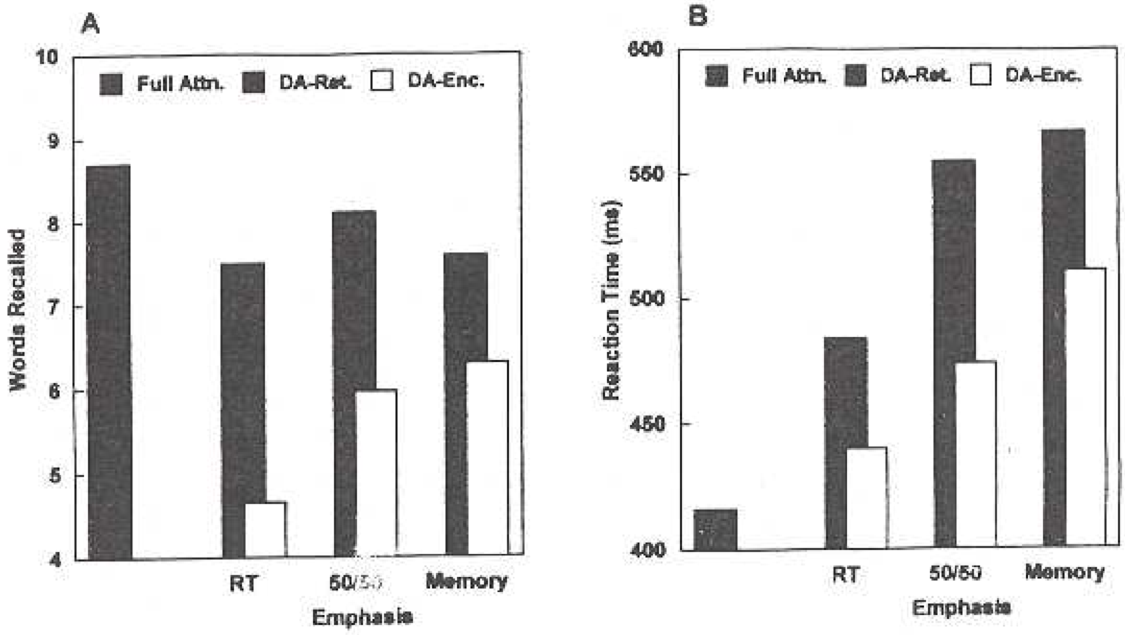

Figure 1. (A) Numbers of words recalled (free recall) under conditions of full attention (Full Attn.) and divided attention at retrieval (DA-Ret.) and encoding (DA-Enc.). Instructions emphasized the reaction-time (RT) task, the memory task, or both tasks equally (50/50). (B) Performance on the continuous RT task under full and divided attention conditions (Experiment 2).

the DA at retrieval conditions, but the different emphasis conditions had no systematic effect on recall performance. A *t* test contrasting free-recall performance under full attention (free–free) and DA at retrieval showed that the drop was reliable, $t(31) = 3.42$, $p < .01$. A similar test contrasting full attention with DA at encoding showed a larger effect, $t(31) = 9.10$, $p < .001$; Figure 1A shows that DA at encoding led to a drop of three items from the free–free level, and that emphasis did have a differential effect in this case. A 2 × 3 ANOVA comparing memory performance under conditions of encoding and retrieval yielded reliable effects of encoding vs. retrieval, $F(1, 31) = 90.8$, $p < .001$, $MSE = 2.31$; of emphasis, $F(2, 62) = 8.53$, $p < .01$, $MSE = 2.12$; and of the interaction, $F(2, 62) = 4.21$, $p < .05$, $MSE = 2.33$.

Figure 1B shows that both DA at encoding and DA at retrieval raised mean RT above the single-task RT mean value of 416 ms, but that DA at retrieval had a substantially greater effect, $t(31) = 6.39$ and 5.62 for encoding and retrieval, respectively, and $p < .001$ in both cases. In the case of RTs, emphasis instructions affected RT values at both encoding and retrieval. An ANOVA on the two DA conditions showed main effects of retrieval versus encoding, $F(1, 31) = 10.1$, $p < .01$, $MSE = 17{,}572$, and of emphasis, $F(2, 62) = 20.5$, $p < .001$, $MSE = 4782$, but no interaction between the variables, $F(2, 62) = 1.74$, $p > .05$, $MSE =$ [illegible]14.

Discussion

The main results of Experiment 2 replicate and extend those of Experiment 1. That is, like Park et al. (1989), we found that a demanding secondary task at retrieval did reduce recall levels but, in essential agreement with Baddeley et al. (1984), that this reduction in recall was substantially less than the reduction associated with DA at encoding. On the other hand, performance on the concurrent task itself was impaired more by DA in the case of retrieval than in the case of encoding; this disruption of a concurrent task by retrieval processing replicates the findings of Johnston et al. (1970), Martin (1970), Trumbo and Milone (1971), and Griffith (1976). Whereas encoding is characterized by trade-offs between the memory and CRT tasks, such that changes in emphasis increase performance levels in one task and reduce them in the other, recall performance at retrieval appears to be privileged or protected, so that it is affected only slightly by the presence of a secondary task and is unaffected by changes in emphasis. Yet it is not possible to argue that retrieval is automatic (cf. Baddeley et al., 1984), given that DA is associated with a small but reliable drop in recall, and that concurrent task RT increases substantially—from a single-task mean of 412 ms to an average DA value of 535 ms.

When encoding and retrieval phases are compared, it seems at first that the differences between them can be characterized as reflecting different trade-offs between the memory and CRT tasks. That is, DA at encoding depresses memory performance but has relatively slight effects on RT performance, whereas the opposite is true for DA at retrieval. However, an explanation in terms of differential trade-offs is not satisfactory on closer inspection. For example, Figure 1 shows that mean RT is faster for DA at retrieval (RT emphasis) than it is for DA at encoding (memory emphasis), yet memory performance is also higher in the former condition. Experiments 3 and 4 shed further light on this point.

A further purpose of Experiment 3 was to compare the retrieval costs associated with paired-associate recall with those of free recall, as found in the first two experiments. The notion of environmental support (Craik, 1983, 1986) suggests that cued recall should normally require smaller amounts of attentional resource than does free recall, and that RT costs should therefore be smaller for paired associates than for free recall during the retrieval phase. By the same logic, RT costs should be even less during DA at retrieval in a recognition test, and this hypothesis was tested in Experiment 4.

Experiment 3

This was a paired-associate study in which each trial consisted of 12 pairs of unrelated nouns presented auditorily. Because of the need to encode two words on each trial, presentation rates were somewhat slower than in Experiments 1 and 2. Presentation was followed by a 30-s arithmetic task, and then by a retrieval phase in which the 12 stimulus words were re-presented auditorily in a different random order and the participant attempted to give each associated response orally. The trials were presented either under full attention or DA conditions. Under full attention conditions, we used different rates of presentation (2, 3, 4.5, and 6 s/pair, respectively) at either encoding or retrieval for the purposes of constructing "calibration curves." In the DA conditions, the word lists were presented auditorily at a 6-s rate (both at encoding and retrieval), and the continuous RT task used in the first two experiments was performed simultaneously, either at encoding or at retrieval. The DA trials were carried out under three different emphasis conditions, as in Experiment 2; participants were asked to emphasize the memory task or the RT task, or to pay equal attention to both tasks. In addition, the RT task was performed on its own to yield a base-rate RT measure, and a press rate measure was also obtained in which no RT decisions were required. Finally, a "repetition task" was carried out in which participants were presented with 12 single words under dual-task conditions; the task was simply to repeat each word as it was presented. The purpose of this task was to assess the effect of output interference (with no memory retrieval) on the CRT task.

Method

Participants. The participants were 32 undergraduate students from the University of Toronto, who took part either for course credit or for money.

Stimuli. The stimuli were 816 two-, three-, and four-syllable common concrete nouns. The 720 test words were randomly paired to form 30 lists of 12 word pairs.

Experimental tasks. The two principal tasks were the CRT task used in the previous two experiments, and paired-associate learning and recall. During the encoding phase of the paired-associate task, word pairs were presented auditorily, either at a 6-s rate in the dual-task conditions or at rates of 2, 3, 4.5, or 6 s/pair in the calibration trials run under single-task conditions. In the retrieval phase of the dual-task conditions, the first words of each pair were presented auditorily at a 6-s rate and in a different random order relative to the presentation order. In the calibration trials, stimulus words were presented at 2, 3, 4.5, or 6 s/word. An arithmetic task was always interpolated between the encoding and retrieval phases. In this task, 30 single digits were presented auditorily at a 1-s rate, and the participants' task was to add 3 to each digit and to report the sum orally. Finally, participants performed a repetition task under dual-task conditions in which single words were presented at a 6-s rate, and the task was simply to repeat each word immediately after its presentation.

Procedure and design. Each person participated in two sessions of about 1 hr each. The same tasks were carried out in each session, but in a different order and with different word lists. Each session started with four practice trials. First, the participant practiced the arithmetic task for 30 s, and then was given a practice paired-associate list under single-task conditions, at a 6-s rate during both encoding and retrieval. The RT task was then performed alone for 60 s, and finally a further memory list was presented for practice under dual-task conditions at both encoding and retrieval.

The main test conditions were run in four blocks, the order of which was counterbalanced across participants. One block consisted of the presentation and recall of four different paired-associate lists presented at either 2, 3, 4.5, or 6 s/pair, but always recalled at a 6-s rate. A second block contained a further four paired-associate lists, always presented at a 6-s rate, but recalled at either 2, 3, 4.5, or 6 s/stimulus word. These two blocks were therefore run under free–free conditions; the data were used to construct calibration curves for encoding and retrieval, respectively. The third and fourth blocks contained dual-task trials. In one (DA–free), three paired-associate lists were presented and recalled at a 6-s rate; encoding was performed concurrently with the CRT task, but retrieval was carried out under single-task conditions. Each of the three lists was run under one of the emphasis conditions (memory, RT, or 50/50). The fourth block also contained three paired-associate trials, but in this case (free–DA) encoding was carried out under single-task conditions and retrieval was performed concurrently with the DA task. Again, one list was run under each of the three emphasis conditions.

Four presentation formats were employed. In Format 1a the order of free–free (calibration) trials was always 2, 3, 4.5, and 6 s. Format 1b used the same word lists as Format 1a, but the lists used for encoding manipulations in Format 1a were used for retrieval manipulations, and vice versa. The order for free–free trials remained 2, 3, 4.5, and 6 s. In Format 2a, the same word pairs were randomly rearranged to make new lists, and the free–free order was 6, 4.5, 3, and 2 s. Format 2b again exchanged lists between encoding and retrieval. In Session 1, the four memory blocks were ordered in all possible ways (ABCD, ABDC, . . . , etc.) for 24 participants; the remaining 8 people were tested using 8 randomly selected orderings. In Session 2, the four memory blocks were presented in the reverse order from Session 1 (e.g., ABCD, then DCBA). In addition, the order of free–free rates was reversed between sessions (e.g., 2, 3, 4.5, and 6 s, then 6, 4.5, 3, and 2 s). Finally, the five nonmemory trials in each session (two RT base-rate trials, two RT press rate trials, and one repetition trial) were performed at the beginning (one base rate and one press rate), in the middle (repetition task), and at the end (one base rate and one press rate) of each session.

Results

Single-task performance. The data from the paired-associate trials run under free–free conditions at different presentation and recall rates are presented in a later section. The one exception is the average recall from free–free trials in which both presentation and recall rates were 6 s. This mean recall value (7.98 words) served as the full attention baseline. For the CRT task, the full attention baseline was 439 ms.

Dual-task performance. Data from the memory and CRT tasks are shown in Figure 2. The memory results are very similar to those from Experiment 2; DA at encoding reduced recall performance substantially relative to the full attention baseline, and performance was sensitive to changes in emphasis. In contrast, DA at retrieval reduced recall by less than one word on average, and performance was not sensitive to the emphasis manipulation. In this experiment, concurrent RT increased by approximately the same amounts in the encoding and retrieval DA conditions, and these two conditions appear to be equally affected by changes in emphasis.

A *t* test contrasting average recall performance in the DA at retrieval conditions with the full attention baseline showed that the drop was reliable, $t(31) = 3.08$, $p < .01$. A similar test contrasting average recall in the DA at encoding conditions with full attention showed a larger effect, $t(31) = 10.18$, $p < .001$. A 2 × 3 ANOVA comparing memory performance under conditions of DA at encoding or retrieval yielded reliable effects of encoding versus retrieval, $F(1, 31) = 56.5$, $p < .001$, $MSE = 3.04$; of emphasis, $F(2, 62) = 12.7$, $p < .001$, $MSE = 1.62$; and of the interaction, $F(2, 62) = 8.82$, $p < .001$, $MSE = 1.44$. For the RT data, average performance was significantly higher than baseline for both encoding, $t(31) = 9.67$, $p < .001$, and retrieval, $t(31) = 6.34$, $p < .001$. An ANOVA on the two DA conditions showed a significant effect of emphasis, $F(2, 62) = 48.5$, $p < .001$, $MSE = 1891$, but no reliable effects of encoding versus retrieval and no interaction (both $Fs < 2.0$).

Discussion

The recall data from Experiment 3 are very similar to those found under free recall in the first two experiments; that is, division of attention at encoding reduced performance substantially, and performance was sensitive to emphasis instructions. These results are in line with the notion that encoding is a controlled process. In contrast, division of attention at retrieval reduced performance to a lesser (but still significant) extent, and in this case performance was not affected by changes in emphasis. These results are in line with the notion (Baddeley et al., 1984) that retrieval is automatic in some respects at least.

The RT data shown in Figure 2 are rather different from those shown for free recall in Figure 1. In the present case DA at encoding is associated with an average DA cost of 77 ms (compared with 55 ms in Experiment 2), and DA at retrieval is now associated with an average cost of 68 ms (compared with 123 ms in Experiment 2). Our explanation of these differences is that encoding costs are higher in Experiment 3 because encoding now involves associating pairs of words, as opposed to encoding single items in the

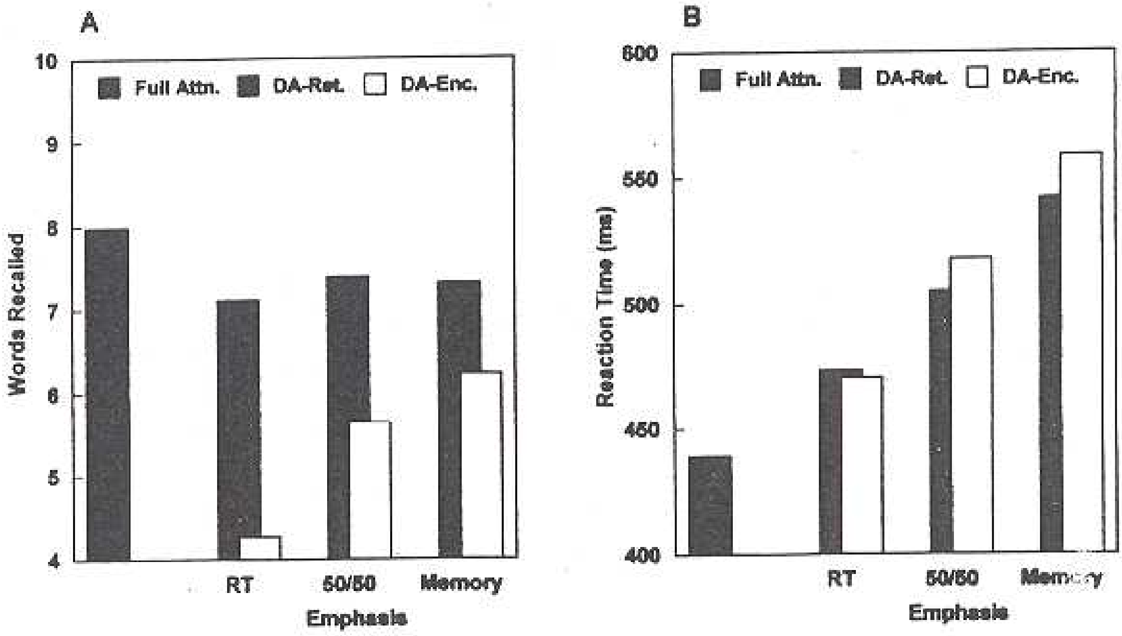

Figure 2. (A) Numbers of words recalled (cued recall) under conditions of full attention (Full Attn.) and divided attention at retrieval (DA-Ret.) and encoding (DA-Enc.). Instructions emphasized the reaction-time (RT) task, the memory task, or both tasks equally (50/50). (B) Performance on the continuous RT task under full and divided attention conditions (Experiment 3).

first two experiments. Retrieval costs are lower in Experiment 3 (as predicted) because of the greater "support" provided by the stimulus word cues. Whereas we understand why encoding costs are higher and retrieval costs are lower relative to free recall, there is no particular reason for encoding and retrieval RT costs to be essentially the same. The fact that they are very similar, however, allows us to make the point that memory performance and concurrent RT performance do not simply trade off against each other in any simple fashion. That is, although concurrent RT costs were approximately equivalent in Experiment 3, DA at encoding still reduces memory performance to a much greater degree than does DA at retrieval.

Experiment 4

This final experiment was very like Experiment 3, but with recognition as the memory test rather than cued recall. We expected that DA at acquisition would be associated with impaired encoding and thus with poorer memory performance; furthermore, these costs should have mimicked those found in Experiments 1 and 2 (single words in all cases). However, DA at retrieval might have caused even less impairment than was found in Experiments 1–3, given that recognition provides greater "retrieval support" than does recall (Craik, 1983; Craik & McDowd, 1987). On each trial 30 unrelated nouns were presented at a 4-s rate. This encoding phase was followed by an arithmetic task (30 s) and then by two recognition test blocks, each consisting of 15 target words and 10 distractors, again presented at a 4-s rate. Recognition was broken into two blocks so that participants would not become too fatigued while performing the concurrent CRT task; target words were assigned randomly to the two blocks. Encoding and retrieval phases were performed either under free–free conditions at a 4-s rate in both phases or concurrently with the CRT task at either encoding (DA–free) or retrieval (free–DA). In addition, free–free trials were run at encoding rates of 1, 2, 3, and 4 s/word (all with 4-s retrieval rates) and at retrieval rates of 1, 2, 3, and 4 s/word (all with 4-s encoding rates); these trials provided the calibration curves for the purpose of assessing trade-offs between memory and RT. CRT-alone trials were performed to establish RT base-rate and motor key-press rates. Finally, a version of the repetition task was run in which participants performed the CRT task while hearing words at a 4-s rate; in this case, the words had not been presented previously and participants said either "yes" or "no" after each word, depending on instructions. The purpose of this task was again to check whether simple vocal responses ("yes" or "no") affected RT performance. The experiment was again run in two sessions.

Method

Participants. The participants were 24 University of Toronto undergraduates, who took part in the experiment either for course credit or for payment.

Materials. In total, 850 common concrete nouns of one, two, three, or four syllables were used over the two experimental sessions. Of the 850 words, 100 were used for practice in Session 1, and 375 were used in each session as test materials.

Procedure. Each participant performed the same tests, but with different materials and in a different order, as described in the *Design* section. All participants first practiced the arithmetic task (20 one-digit numbers presented auditorily at a 1.5-s rate; the participants added 3 to each digit and gave the answer orally). The memory task was then explained and practiced; 30 words were presented auditorily at a 4-s rate, followed by the 30-s arithmetic task and then by the recognition test phase. For this practice trial, each of the two recognition blocks consisted of 15 targets and 10 distractors presented auditorily at a 1-s rate; the participant responded "yes" or "no" orally after each test word to indicate whether or not each word was a target. The CRT task was then described and practiced for 30 s, followed by a 40-s practice of the press rate task—that is, continuing to press the four keys as rapidly as possible for 5 s each (twice). The final practice trial was run under dual-task conditions at both encoding and retrieval. Before the encoding phase began, a beep signaled the participant to start the CRT task; 4 s later, 30 words were presented auditorily at a 4-s rate. The arithmetic task (30 s) followed the encoding phase; then another beep signaled the participant to recommence the CRT task, followed after 4 s by the first recognition test blocks (15 targets + 10 distractors presented auditorily at a 4-s rate). In turn, another 30-s arithmetic task was performed, followed by the second recognition block, also under dual-task conditions.

After practice, given only during the first session, each participant performed the following tests in each session: two trials of the CRT task alone, one for 120 s (the length of the encoding phase) and one for 100 s (the length of the retrieval phase); two trials of the press rate task (one for 120 s and one for 100 s); two trials of the memory task alone (free–free) with encoding rate varied; two trials of the memory task alone (free–free) with retrieval rate varied; one trial of the repetition task; one or two DA–free trials (i.e., one or two of the three emphasis conditions, memory, 50/50, and RT); and two or one free–DA trials, such that three dual-task trials were carried out in each session.

Design. The pool of 750 words was used to form two complete sets of word lists; 12 of the participants were given one set (Format 1) and 12 were given the alternate set (Format 2). In addition, each format was split into two versions, such that the words used in encoding variations in one version (for six participants) were used for retrieval variations in the second version (for the remaining six participants). Thus, four different sets of words were associated with each condition across the experiment.

With regard to the order of presentation of tasks, each participant carried out the tasks in a different order governed by the 24 permutations of the 4 major task types: free–free (encoding rate varied), free–free (retrieval rate varied), DA–free, and free–DA. Each participant performed the tasks in one order in Session 1 and then in the reverse order in Session 2. The sessions were at least 24 hr apart. On each occasion the repetition task was always presented in the middle of the session. The two RT-alone trials and the two press rate trials were distributed across each session, and their order was also counterbalanced from Session 1 to Session 2.

Results

The recognition and RT results are shown in Figures 3A and 3B, respectively. The recognition data (hits minus false alarms) show that DA at encoding reduced performance from the free–free level of 76%, and that shifting the emphasis from memory to RT was associated with a further

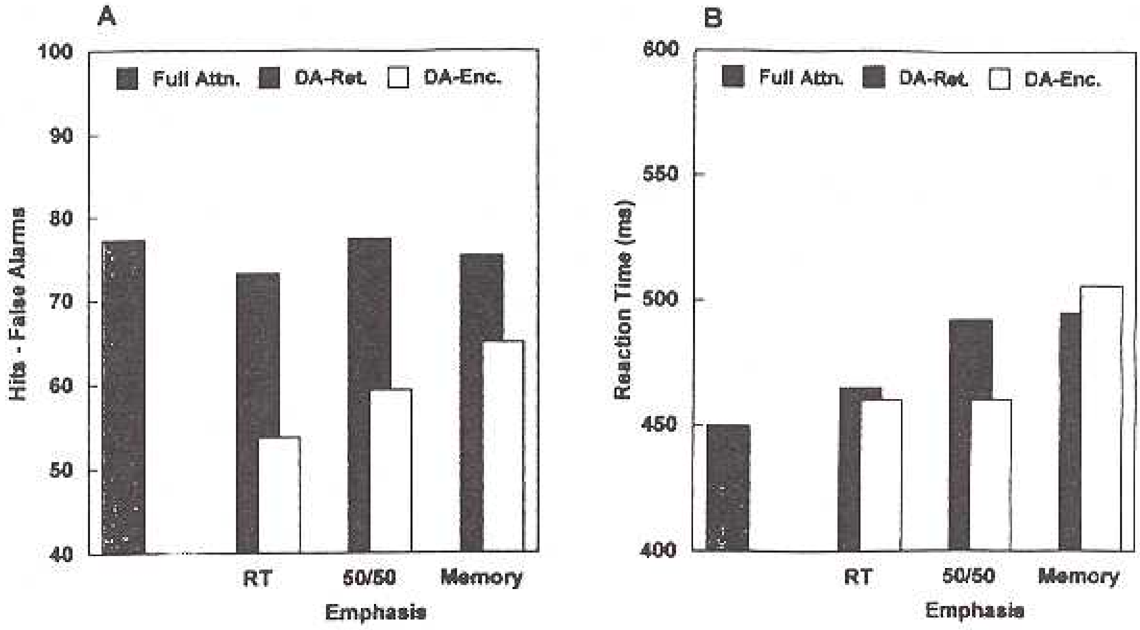

Figure 3. (A) Proportions of words recognized (hits minus false alarms) under conditions of full attention (Full Attn.) and divided attention at retrieval (DA-Ret.) and encoding (DA-Enc.). Instructions emphasized the reaction-time (RT) task, the memory task, or both tasks equally (50/50). (B) Performance on the continuous RT task under full and divided attention conditions (Experiment 4).

drop in performance. In contrast, DA at retrieval had very little effect on memory performance relative to the free–free condition. The RT data show again that dual-task performance was associated with an increase in RT above the free–free baseline (shown here as 450 ms, the average of the RT encoding baseline conditions run for 120 s and the RT retrieval baseline conditions run for 100 s; these two component means were 448 and 452 ms, respectively). RT costs were greatest for the memory emphasis conditions, and declined for the 50/50 and RT conditions.

Statistical tests on the recognition memory data showed first that DA at encoding (collapsed over the three emphasis conditions) was associated with a reliable drop in performance, $t(23) = 6.61, p < .001$ (means of 76% and 59% for free–free and DA at encoding, respectively). The difference between the average performance during DA at retrieval (75%) and free–free was not significant, $t(23) = 0.36$. A 2 × 3 ANOVA (Encoding/Retrieval × Emphasis) revealed reliable effects of encoding versus retrieval, $F(1, 23) = 39.32, p < .001, MSE = 233$, and of emphasis, $F(2, 46) = 3.22, p < .05, MSE = 182$. In this case the interaction was not reliable, $F(2, 46) = 1.54, p > .05, MSE = 187$, although a further 2 × 2 ANOVA involving only the two extreme emphasis conditions did show a reliable interaction, $F(1, 23) = 4.85, p < .05$.

Corresponding tests on the RT data shown in Figure 3B showed first that average RT at encoding (collapsed over emphasis) was reliably higher than the RT baseline value (means of 475 and 448 ms, respectively), $t(23) = 2.87, p < .01$. Also, average RT at retrieval was reliably higher than its baseline value (means of 484 and 452 ms, respectively), $t(23) = 2.55, p < .02$. A 2 × 3 ANOVA (Encoding/Retrieval × Emphasis) carried out on RTs showed no reliable effect of encoding/retrieval, $F < 1.0$; a reliable effect of emphasis, $F(2, 46) = 12.30, p < .001, MSE = 1444$; and a marginal interaction, $F(2, 46) = 2.79, p < .10, MSE = 2006$. Finally, the average RT on repetition trials ("retrieval" trials in which the participant responded "yes" to every word or "no" to every word) was 459 ms; this value did not differ significantly from the baseline value of 452 ms, $t(23) = 0.95, p > .05$.

Discussion

The pattern of results found in this recognition memory study is essentially similar to the pattern found with paired associates in Experiment 3, although with some differences. First, although DA at encoding was again associated with a large reduction in performance, DA at retrieval did not reduce performance from the single-task level (Figure 3A). Thus, we did replicate this aspect of the results of Baddeley et al. (1984) in the present experiment in which the test was recognition. As in Experiments 2 and 3, the emphasis manipulation had a systematic effect on encoding but not on retrieval, although in this case the interaction between emphasis and encoding/retrieval was reliable only when the extreme emphasis conditions were considered.

With regard to the RT results, the costs associated with DA at retrieval were not reliably greater than those associated with encoding; this result is similar to the findings from paired-associate recall (Experiment 3), but differs from the results of the free-recall studies (Experiments 1 and 2). RT costs were again sensitive to the emphasis manipulation, showing that costs declined as the RT task received greater emphasis. A final result of note is that RT in the repetition task rose from the baseline level only marginally (7 ms/press), so it may be concluded that RT costs at retrieval are not attributable to simple output conflicts. Rather, the actual processes of retrieval must underlie the significant costs incurred in the dual-task situation.

Table 3 shows the memory costs and RT costs in all four experiments. *Memory costs* refers to the percentage drop from the free–free control condition in all cases; *RT costs* refers to the slowing of RT above baseline. Memory costs are greater for encoding than for retrieval in all cases. Memory performance is affected by DA at encoding in all paradigms, whereas the smaller costs of DA at retrieval are further reduced in cued recall and recognition; arguably, they are reduced as retrieval support increases. RT costs at retrieval are also reduced systematically from free recall to cued recall to recognition. The RT costs associated with encoding range from 27 to 55 ms/key press when single words were encoded, but rise to 77 ms in the case of word pairs.

The Shared Time Model of Memory and RT

As described in the introduction, one purpose of the present series of studies was to explore the possibility that memory performance under dual-task conditions reflects the encoding and retrieval operations carried out in the time "provided" by slowing of the RT task. In Experiments 1, 3, and 4, we examined this hypothesis by constructing calibration curves for free recall, cued recall, and recognition, respectively.[2] To do this we varied the time available for encoding and retrieval under single-task conditions, and plotted memory performance as a function of available time. We then calculated the time "saved" from the RT task (i.e., the amount of slowing) under dual-task conditions, and entered this time on the relevant calibration curve to see whether the curve predicted the actual memory performance obtained under DA conditions. We thus made the simplifying assumption that processing of the memory task and the RT task cannot proceed in parallel, and that memory performance depends simply on how much time is allocated to a task. For example, if mean RT under single-task conditions is 500 ms and this mean value rises to 800 ms under dual-task conditions at encoding, it is assumed that 300 ms are available for memory encoding processes. If the encoding phase lasts 60 s, then 75 RT responses are made (60 s/800 ms), and so 75 × 300 ms = 22.5 s is supposedly available for memory encoding. The validity of this model may then be checked by comparing the recall level predicted by the calibration curve (i.e., the recall level corresponding to 22.5 s total encoding time) with the level of recall actually obtained in the DA phase of the task.

Table 3
Memory Costs (Percentage Drop From Free–Free Performance) and RT Costs (RT in Milliseconds Above Baseline) Under Divided Attention Conditions in the Four Experiments

	Memory costs		RT costs	
Experiment	Encoding	Retrieval	Encoding	Retrieval
1 (free recall)	46	13	42	146
2 (free recall)	35	11	55	123
3 (cued recall)	33	09	77	68
4 (recognition)	22	01	27	32

Note. RT = reaction time.

Retrieval processes were evaluated in exactly the same way in Experiments 3 and 4, by means of the calibration curves constructed by varying the rate of presentation of retrieval cues (Experiment 3) or items to be recognized (Experiment 4). In Experiment 1 (free recall), we assessed a possible trade-off between RT and retrieval processes by employing the same logic to the data from the free–DA condition (DA at retrieval). In this case the equivalence function relating time to memory performance was calculated from the cumulative recall data over the 30-s recall period. The computer-recorded auditory beeps along with the participant's tape-recorded oral recall responses at 2.5 and 5 s, and at 5-s intervals up to the 30-s limit. This procedure allowed us to construct the cumulative recall curve for the four calibration task conditions, shown in Figure 4B. The functions are again negatively accelerated, in line with previous reports of free-recall output over time (Roediger, Payne, Gillespie, & Lean, 1982); the best-fit exponential functions were calculated, relating the growth of recall to the time available.

No calibration curve data were collected in the second free-recall experiment (Experiment 2), but because the conditions of encoding were the same as those used in Experiment 1, it is possible to compare the observed results from Experiment 2 with the results predicted from the group data from the first experiment. In all cases the calculations and statistical tests are given in the Appendix.

It became clear from the results of Experiment 1 that a straightforward application of the calibration logic did not yield good fits to the observed recall values. For encoding, the predicted and observed recall values were 1.5 and 5.1 words, respectively, and for retrieval the values were 4.6 and 8.2 words, respectively. However, a further possibility is that participants can also use the mechanical motor time in each RT response for encoding or retrieval processes; only the decision time is unavailable. It was assumed that press rate RTs provide an estimate of this motor component, and so a further 182 ms/RT response was added to encoding and retrieval times. As detailed in the Appendix, when this was done the predicted and observed encoding values for Experiment 1 were 6.2 and 5.1 words, respectively, and the corresponding retrieval values were 7.3 and 8.2 words. Adding motor time to the calculation thus improves somewhat the fit between observed and predicted; this addition

[2] This method was devised by Richard Govoni and first used in an unpublished experiment in 1993.

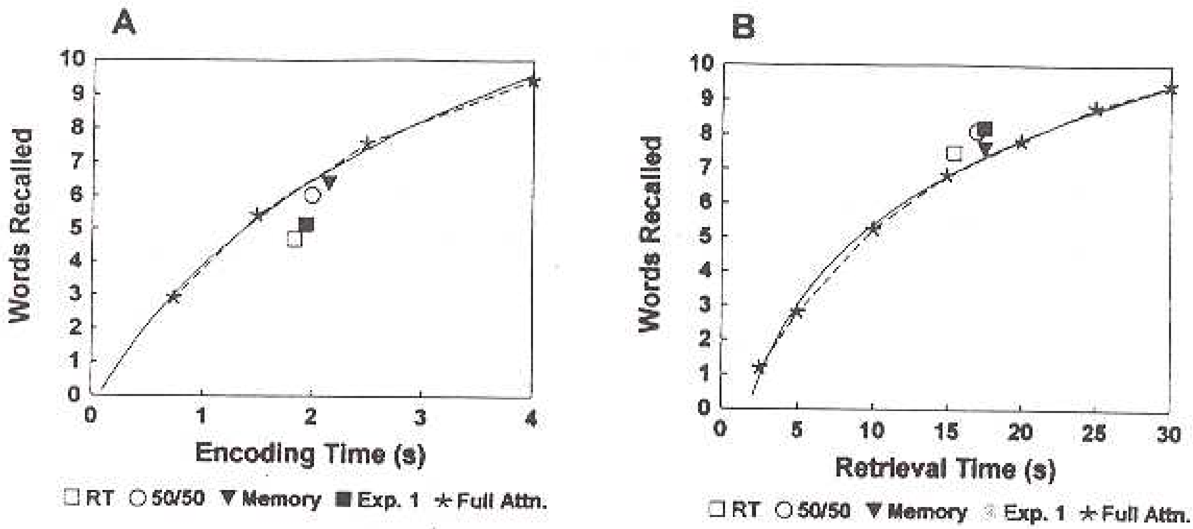

Figure 4. Free-recall functions for encoding (A) and retrieval (B), plotting words recalled as a function of time available. In both cases dashed lines link calibration points, and solid lines are the best-fit functions. The individual points represent mean recall values under divided attention conditions for the three different emphasis instructions in Experiment 2 and the divided attention conditions in Experiment 1 (Exp. 1). RT = reaction time; 50/50 indicates equal emphasis on memory and RT tasks; Full Attn. = full attention.

was also incorporated into the calculations for the remaining experiments.

Figures 4A and 4B show the calibration functions calculated for encoding and retrieval in Experiment 1. The encoding version (Figure 4A) shows that recall levels rise in a negatively accelerated fashion as a function of presentation time. Our data are thus in good agreement with results reported by Roberts (1972). An exponential function based on natural logarithms provided the best fit to the data, and this is the function shown in Figure 4A. As described in the previous paragraph, the observed recall value in Experiment 1 falls below the predicted curve, suggesting that not all of the motor time is available for encoding processes or perhaps that the division of attention between two tasks itself requires attentional resources that are therefore not available for memory. Figure 4A also shows the encoding data from the three emphasis conditions of Experiment 2. The three observed recall values again fall below the predicted curve, and it seems that these values depart systematically from the calibration function as the emphasis shifts from memory encoding to the RT task.

The corresponding retrieval function and observed recall values under conditions of DA at retrieval are shown in Figure 4B. In this case the observed values for both Experiments 1 and 2 fall above the calibration function, suggesting some degree of parallel processing between retrieval and performance of the RT task. The main point to emphasize, however, is that the patterns for encoding and retrieval (comparing Figures 4A and 4B) are very different.

The paired-associate paradigm used in Experiment 3 allows a more precise test of the shared time model at retrieval, because retrieval time can be varied in exactly the same way as encoding time. In this experiment, therefore, calibration curves were constructed by measuring recall under single-task conditions both when presentation rate was varied (2, 3, 4.5, and 6 s/word pair) and when the time available for retrieval was varied (again 2, 3, 4.5, and 6 s/cue word). When encoding time was varied at presentation, the retrieval rate was always 6 s; similarly, encoding time was always 6 s/pair when retrieval rate was varied. In this case linear functions provided a reasonably good fit to the four observed calibration values; the resulting functions are shown in Figure 5. The figure also shows the actual recall data from DA at encoding (Figure 5A) and DA at retrieval (Figure 5B) for the three emphasis conditions, calculated with the addition of motor time. In the case of DA at encoding, memory emphasis fits well, but the other two points fall off more steeply than predicted. For DA at retrieval the three points are above the predicted function, but more or less parallel to it. Again, the encoding and retrieval patterns are very different.

In the recognition memory experiment (Experiment 4), DA conditions were run at a 4-s rate, and data for the calibration curves were collected at encoding rates of 1, 2, 3, and 4 s (with a constant retrieval rate of 4 s) and at retrieval rates of 1, 2, 3, and 4 s (with a constant encoding rate of 4 s). The resulting values are shown in Figure 6, again fitted by a linear function through the four calibration values in each case. Functional encoding and retrieval times were calculated as before, and Figure 6 shows the values for encoding (Figure 6A) and retrieval (Figure 6B). As with the previous experiments the values calculated without motor times added did not fit the predicted curve well, but values with motor times added were again better, and these are the values shown in Figure 6. In the case of encoding, the memory condition fits well, but the other two conditions fall

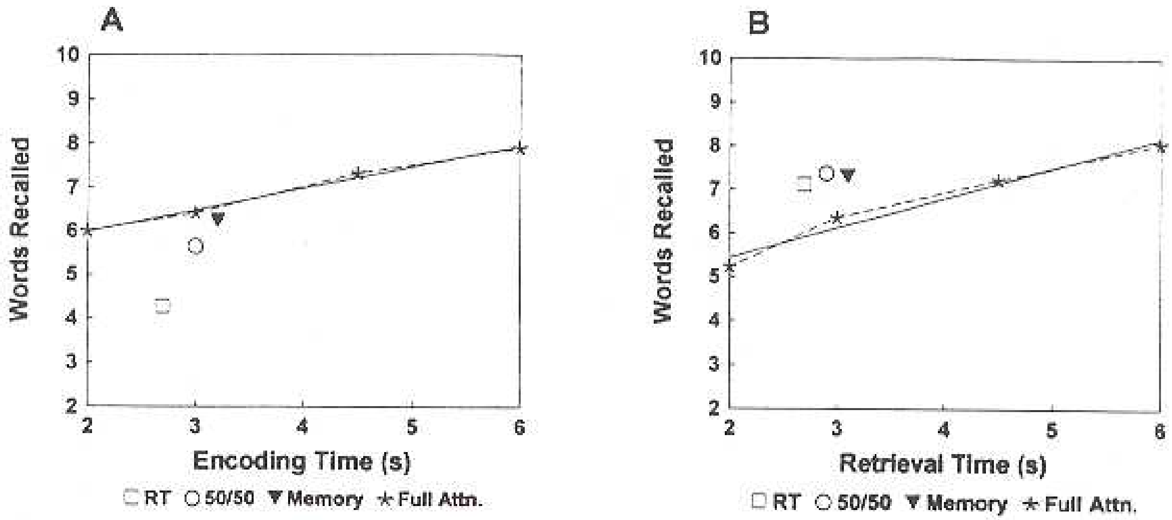

Figure 5. Cued recall functions for encoding (A) and retrieval (B) plotting words recalled as a function of time available. In both cases dashed lines link calibration points, and solid lines are the best-fit functions. The individual points represent mean recall values under divided attention conditions for the three different emphasis instructions in Experiment 3. RT = reaction time; 50/50 indicates equal emphasis on RT and memory tasks; Full Attn. = full attention.

off steeply. For retrieval, all points give reasonable fits. The patterns of encoding and retrieval are similar to the corresponding patterns in the earlier experiments; that is, the observed values for DA at encoding fall progressively below the predicted function as emphasis shifts from memory to RT, whereas the values for DA at retrieval tend to cluster above the predicted function.

It is clear from the results of four experiments that the simple model, in which the time saved by slowing of the RT task is the only time used for memory processing, is not satisfactory. However, with the additional assumption that the motor time component of the RT task can also be used by encoding and retrieval processes, the fits between the predicted functions and observed values are somewhat better. In the case of retrieval, only Experiments 1 and 3 showed a reliable difference between predicted and observed values. Also, observed values were consistently higher than predicted values, suggesting that RT and retrieval processing can be carried out in parallel to some degree. Largely, however, the level of retrieval under DA

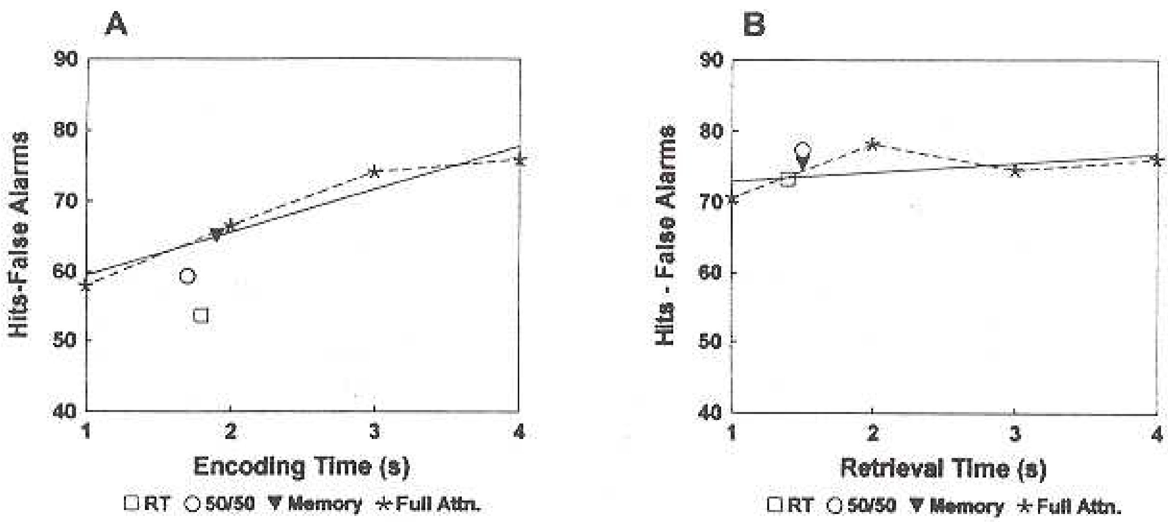

Figure 6. Recognition functions for encoding (A) and retrieval (B), plotting words recognized as a function of time available. In both cases dashed lines link calibration points, and solid lines are the best-fit functions. The individual points represent mean recognition values under divided attention conditions for the three different emphasis instructions in Experiment 4. RT = reaction time; 50/50 indicates equal emphasis on RT and memory tasks; Full Attn. = full attention.

conditions is accounted for by the time "donated" to retrieval processing by the slowing of the RT task.

Division of attention at encoding yields a different picture. In Experiment 2, the effect of emphasis was to drop observed values progressively farther below predicted values from memory to RT emphasis, and this same effect was observed in Experiments 3 and 4. In Experiments 2, 3, and 4, the RT condition gave observed values that were reliably lower than predicted values in all three cases; in Experiment 1, in which the instructions were to emphasize the RT task, the observed value was also reliably lower than the predicted value. One line of speculation is that the qualitative type of encoding changes from memory to RT. It seems possible that as resources are withdrawn the participant must employ shallower types of encoding in the sense of Craik and Lockhart (1972), and that subsequent memory performance is therefore lower than it ought to be if the participant had used the available time to carry out deeper, semantic processing.

A further noteworthy set of findings concerns the correlations between observed and predicted values. The correlations for all four experiments are shown in Table 4. It may be seen that all 20 correlations are positive, and that 16 of the 20 are significant at $p < .05$ or better. The correlations are relatively low in Experiment 2, but in this case participants' observed values were correlated with values predicted from the group data in Experiment 1. In other cases participants' observed values were correlated with predicted values calculated from their own calibration data, and the average value of r was +0.72. This pattern may be contrasted to the pattern obtained when individuals' RT costs were correlated directly with their corresponding memory costs; in this case all 20 correlations were nonsignificant, and the average correlation was +0.08. It seems then that although there is no direct tradeoff between the RT and memory tasks, time saved from the RT task does correlate with memory performance in terms of the participant's own calibration function.

General Discussion

Empirical Results

To recapitulate our major findings briefly, four experiments confirmed many previous results by showing that division of attention during the encoding phase of a memory task reduced performance markedly. This result was found for free recall, paired-associate learning, and recognition memory. For these conditions, examining DA at encoding, performance on the concurrent RT task slowed reliably, especially in the case of paired associates. Division of attention at retrieval yielded a substantially different picture; memory performance was reduced reliably for free recall and cued recall (paired associates), but was not affected for recognition. In all cases, however, the reduction in performance was much less than with DA at encoding. The corresponding RT costs were statistically reliable in all experiments, but costs decreased from an average of 135 ms/key press for free recall to values of 68 and 32 ms for cued recall and recognition, respectively. One further general result was that mere repetition of a single word had no effect on concurrent RT, showing that retrieval costs are not attributable to simple response conflicts (McLeod & Posner, 1984).

Table 4
Product–Moment Correlation Coefficients Between Observed and Predicted Memory Values in the Four Experiments, for RT, 50/50, and Memory Emphasis Instructions

	DA at encoding			DA at retrieval		
Experiment	RT	50/50	Memory	RT	50/50	Memory
1	.60*			.66*		
2	.27	.37*	.37	.58	.32	.33*
3	.75*	.92*	.84*	.87*	.83*	.76*
4	.46*	.35	.71*	.71*	.79*	.78*

Note. DA = divided attention; RT = reaction time.
* $p < .05$.

In Experiments 2, 3, and 4, participants were instructed to emphasize either the memory task, the RT task, or both tasks equally under dual-task conditions. For CRT task performance, greater emphasis on the RT task was associated with faster RTs (or smaller RT costs) in all three experiments, and this effect was equivalent for DA at encoding and DA at retrieval. In the case of memory performance, emphasis affected performance systematically for DA at encoding, but not for DA at retrieval. We took the latter result to mean that encoding processes are subject to strategic control, and that reduced attention is systematically related to reduced memory performance, but that this relationship does not hold for retrieval processes, suggesting that they are more autonomous or automatic in nature.

These basic results thus confirm and extend the previously reported findings of Johnston and his colleagues (e.g., Johnston et al., 1970, 1972) and of Baddeley et al. (1984). That is, division of attention at encoding reduces memory performance substantially, but division of attention at retrieval has either smaller effects (in the case of recall) or no effect (in the case of recognition). At the same time, secondary task costs are much greater for DA at retrieval than DA at encoding for free recall, and these costs are substantial but equivalent for encoding and retrieval in the cases of paired associates and recognition memory (Table 3).

The pattern of results is easy to understand for DA at encoding. Such encoding processes are consciously controlled and attention demanding, and therefore division of attention is associated with a reduction in memory performance and also with a slowing of concurrent RT. Moreover, changes in emphasis are reflected by systematic and complementary changes in both tasks. For DA at retrieval the story is more complex, however. For free recall, comparatively small decreases in memory are associated with comparatively large increases in concurrent RT, suggesting a straightforward trade-off relationship, but this account is not supported by the finding that a change in emphasis from memory to RT is accompanied by a speeding up of RT without any change in memory performance (Experiments 2, 3, and 4). Furthermore, the finding of no reduction in memory performance for DA at retrieval in the case of recognition cannot be taken as evidence for the automatic nature of retrieval processes (cf. Baddeley et al., 1984) given the coexistence of highly reliable RT costs on the concurrent task.

A further major purpose of our experiments was to explore possible trade-offs between the dual tasks by constructing functions linking processing time to memory performance. When the observed values for recall and recognition were plotted in terms of time available from the slowing of the RT task (Figures 4, 5, and 6), we found that the observed values fell below the calibration functions in the case of DA at encoding, but above the functions in the case of DA at retrieval. For encoding, therefore, memory levels are lower than they should be, given the time available, especially under conditions of RT emphasis. Speculative explanations of the discrepancy include the possibility that not all of the motor time is available for memory processing or that management of the division of attention at encoding itself requires attentional resources. A third possibility is that participants are unable to encode the words deeply enough under dual-task conditions—especially in the case of RT emphasis—and that this shift in the qualitative type of encoding leads to poorer recall and recognition. In the case of DA at retrieval, the observed values all lie above the calibration functions. That is, performance is better than predicted from a consideration of the time available, suggesting that some degree of parallel processing is possible between memory retrieval and performance of the RT task. It is also noteworthy that the correlations between observed and predicted values are consistently high (Table 4). Thus, even when the absolute levels of recall or recognition deviate from predicted values, greater slowing of the RT task is related to higher levels of memory performance. It may therefore be concluded that both encoding and retrieval operations require time, and that when more time is donated by greater amounts of RT slowing, memory performance can be sustained at a higher level. Note that this conclusion is as valid for retrieval as it is for encoding (Table 4). Perhaps the most important message conveyed by the results shown in Figures 4–6, however, is that encoding and retrieval processes under dual-task conditions show very different patterns with respect to the functions relating time to memory processes.

What can be interpreted from RT costs in the experiments? At encoding, the answer appears to be straightforward: Greater RT costs are associated with higher levels of memory performance, suggesting that encoding operations are controlled as opposed to automatic, and that they therefore divert some processing resources from the RT task. In line with this suggestion, when the memory task was emphasized in Experiments 2, 3, and 4, memory performance improved and RTs were slowed relative to emphasis on the RT task. Also, RT costs were greater when pairs of words were encoded in Experiment 3, as opposed to single words in the other experiments (Table 3); plausibly, richer encoding operations are possible for word pairs. It is also likely that some part of RT costs at encoding is associated with the management of division of attention, although it is impossible to separate these costs from those associated with encoding per se. The interpretation of RT costs at retrieval is more challenging. We suggested earlier that postretrieval editing is not a major component of these costs, given that the costs did not vary systematically as a function of number of words retrieved (Table 2). We did suggest that RT costs may be associated with the placement of the cognitive system into a retrieval mode (Tulving, 1983), but other components may also be operating; for example, voluntary, strategic operations may elaborate and augment the retrieval information provided, especially when this information is minimal, as in free recall. Again, it seems likely that some costs are required to manage the division of attention between tasks.

Our results fit well with the suggestions of Jacoby and his colleagues that memory retrieval processes involve separable automatic and controlled processes; the former is associated with feelings of familiarity and the latter with deliberate and effortful processes of conscious recollection (Jacoby, 1991). In experiments similar to the present series, Jacoby, Woloshyn, and Kelley (1989) examined the effects of dividing attention during the study and test phases of a fame judgment task. They found that divided attention reduced the conscious recollection component but did not affect familiarity. The implication for our results is that if retrieval can be performed on the basis of familiarity, it requires only small amounts of attentional resources and is therefore relatively unaffected by division of attention. Arguably, recognition memory fits this description. On the other hand, free recall presumably relies largely on conscious recollection, which does require resources. The pattern of RT costs shown in Table 3 corresponds nicely to this analysis.

Before turning to more theoretical issues, it should be pointed out that a procedural difference between DA at encoding and DA at retrieval may underlie some of the observed effects. The difference is that the timing of processing is more under the participant's control during retrieval than during encoding. That is, at encoding, each item must be processed when it is presented, whereas at retrieval the participant can choose when to apply retrieval effort and may be able to schedule responses in a way that accommodates the RT task.[3] This notion requires further experimentation to confirm or disconfirm, but we consider it unlikely in light of the present evidence. First, the alternative account suggests that if the participant can schedule his or her responses more efficiently at retrieval than at encoding, then RT costs should be less at retrieval, whereas in fact they are substantially greater, in free recall at least. Second, the same general pattern of greater memory costs associated with DA at encoding than at retrieval was found with paired associates and recognition (Experiments 3 and 4), and in these cases we presented the retrieval cues or recognition items at the same fixed rates as at encoding. Third, Baddeley et al. (1984, Experiment 3) reported a study in which the items in

[3] This point was suggested to us by a reviewer of a previous version of this article.

the presentation list were shown simultaneously rather than serially; that is, all words to be learned were presented on a card for 48 s. Under these conditions, participants can also schedule their encoding operations, yet the pattern of results did not change—DA again had a greater disruptive effect on memory performance at encoding than at retrieval.

Evidence From Neuropsychology

Our results are consistent with evidence and models emerging from the literature on neuropsychology and neuroscience. Moscovitch (1992, 1994; Moscovitch & Umilta, 1990) has proposed that episodic memory performance is mediated by two principal components: a modular medial temporal/hippocampal component whose operations are essentially automatic, and a frontal-lobe component whose operations are strategic, organizational, and accessible to consciousness and voluntary control. Aspects of this proposal have been supported by the results of studies using positron emission tomography (PET); for example Kapur et al. (1994) reported that deep encoding operations were associated with activation of the left dorsolateral prefrontal region, and Shallice et al. (1994) showed that activation in this same region during memory encoding was eliminated by the performance of a difficult concurrent distraction task. Another finding from the PET literature that bears on the present issues is the observation that whereas encoding processes in episodic memory are associated with activation of areas in the left prefrontal cortex, episodic memory retrieval processes are associated with right prefrontal activation (Nyberg, Cabeza, & Tulving, 1996; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994). This consistent finding of a hemispheric encoding–retrieval asymmetry (the HERA model; Tulving et al., 1994) underlines the conclusion that encoding and retrieval processes differ in some important respects at least. We therefore propose that the memory encoding operations studied in our experiments are mediated substantially by the frontal lobes (perhaps primarily by left frontal areas) and are subject both to conscious control and to disruption from a secondary task. Once the consciously controlled aspects of encoding are complete, the medial temporal/hippocampal structures automatically pick up and store the information.

The notion of retrieval mode is also supported by recent evidence from PET studies; Kapur et al. (1995) found that the active attempt to retrieve was associated with activation in right frontal regions, regardless of whether memory targets were present. The same conclusion was reached in a recognition memory study using the PET technique by Nyberg, Tulving, et al. (1995). This same right frontal region has also been observed to be active in other studies of episodic memory retrieval (Shallice et al., 1994; Tulving, et al., 1994). It is unlikely, however, that retrieval mode accounts for all of the RT costs at retrieval in our studies; for example, why should retrieval mode costs decline as emphasis shifts from memory to RT, and why should they increase from recognition to free recall (Table 3)? However, this latter result does fit well with Moscovitch's (1992) suggestion of a strategic, frontal component whose function is to elaborate and augment retrieval information before applying it to the relatively automatic medial temporal/hippocampal system; such augmentation is least necessary in the case of recognition and most necessary for free recall. By the same token, it is unlikely that changes in emphasis affect this strategic component, because such changes would affect memory performance systematically, but did not in our experiments (Figures 1–3). Instead, we speculate that the relatively large RT costs observed at retrieval under memory emphasis conditions are unnecessary, and would perhaps decline with extended practice. That is, some resources allocated either to the retrieval mode or to the management of division of attention are not essential to the efficiency of retrieval processes. This allocation of resources causes slowing of the RT task but does not enhance memory, and so when the resources are reallocated under RT emphasis, performance on the CRT task speeds up without causing a compensatory drop in memory.

Encoding and Retrieval: Same or Different?

At the beginning of this article, we argued that encoding and retrieval processes appear to be very similar, or to share features, both from the perspective of cognitive theory (Bransford et al., 1979; Kolers, 1973; Roediger et al., 1989; Tulving & Thomson, 1973) and from the viewpoint of cognitive neuroscience (Mishkin & Appenzeller, 1987; Moscovitch, Kapur, Köhler, & Houle, 1995; Squire et al., 1984). In fact, some degree of overlap between encoding and retrieval processes is presumably necessary, given that the subject of both initial encoding and subsequent retrieval is the same set of experienced events. Despite this convergence of views, our results show many more differences than similarities between the two processes. In summary, the main points of difference were

1. Division of attention was associated with a much greater drop in memory performance when attention was divided at encoding than at retrieval.
2. Changes in emphasis instructions had substantial effects on memory at encoding, but none at retrieval.
3. Concurrent RT costs were greater at retrieval than at encoding (for free recall).
4. The calibration functions were very different for encoding and retrieval (Figures 4–6), yet they were consistent across experiments. They suggested some degree of parallel processing at retrieval but none at encoding.

Taken together with previous reports of a relative invulnerability of retrieval processes to DA (Baddeley et al., 1984) and to the effects of alcohol and other drugs (Birnbaum & Parker, 1977; Curran, 1991), our results lend support to the argument that encoding processes are controlled, whereas retrieval processes have a substantially automatic component. Other indications of differences between encoding and retrieval come from reports of differential frontal-lobe involvement in the two processes (Tulving et al., 1994), and from psychophysiological evidence that deep processing is associated with lower heart rate variability at retrieval but not at encoding (Vincent, Craik, & Furedy, 1996).

How are these empirical differences to be reconciled with the theoretical and empirical similarities listed previously? One possibility is that the final mental (and cortical) representations of events are very similar at encoding and retrieval, but the control processes involved in laying down and reactivating the representations are substantially different. According to the available evidence, these representations are located in a variety of posterior cortical areas, depending on the qualitative nature of the information represented (e.g., Squire, 1987), whereas the control processes may be mediated by frontal areas (Moscovitch & Umilta, 1990). This suggestion is consonant with the observation that the same general areas of the brain are activated during learning and retrieval (Mishkin & Appenzeller, 1987; Moscovitch et al., 1995; Squire, 1992), yet it is also in line with the observation that different frontal areas are involved at encoding and retrieval (Kapur et al., 1995; Tulving et al., 1994).

We suggest therefore that memory encoding processes are essentially those involved in the perception and comprehension of external events. These encoding processes require conscious awareness and vary in their resource requirements, depending on such factors as the familiarity or novelty of the stimuli, their compatibility with prior learning, and their importance to the observer. The encoding operations can be augmented by further elaborate processing (corresponding roughly to the "amount of attention paid" to the stimulus), and such further processing requires additional processing resources that are as a consequence withdrawn from any concurrent task. Following the suggestion in Moscovitch (1992), the resulting mix of stimulus-driven and self-initiated operations are applied to the medial temporal/hippocampal system, which in turn binds corresponding representations in appropriate cortical areas.

Retrieval is initiated either by the presentation of an explicit retrieval cue, by self-generated cues in response to a very general memory query (e.g., "recall the words from the recently presented list"), or simply by stimuli encoded in the normal course of perception. This last case is necessary to account for the everyday phenomenon of involuntary recollection (Richardson-Klavehn, Gardiner, & Java, 1996). When retrieval is intentional, it has been suggested that some attentional resources are required to establish and maintain a retrieval mode within the cognitive system (Kapur et al., 1995; Tulving, 1983). In addition, it is likely that the retrieval information presented will be inadequate to invoke recollection by itself, and that further resource-demanding operations must therefore be carried out. Such additional processing is most likely to be required for free recall, and least likely to be required for recognition. The resulting mix of presented and self-generated information is applied to the medial temporal/hippocampal system, which then automatically reactivates stored representations fitting the "description" specified by the retrieval information. This set of suggestions thus gives a plausible account of our results: Retrieval mode is in operation in all three paradigms, and is unaffected by the number of items actually retrieved (Table 2). Cue elaboration is required especially for free and cued recall, thereby adding to concurrent task costs in these cases. Finally, there may be a cost associated with the management of dual-task processing, and we speculatively suggested that a switch in emphasis from memory to RT can reduce the resource allocated to this function without resulting in any decrement in memory performance.

Is episodic memory retrieval automatic, as proposed by Baddeley et al. (1984)? Our results suggest a more complicated picture. In the case of recognition memory under RT emphasis, the answer is substantially "yes"; in this case memory performance is unaffected by division of attention, and concurrent task performance is affected only slightly. As the paradigm shifts from recognition through cued recall to free recall, the conclusion also changes, however. Division of attention is associated with some drop in memory performance for cued recall (Experiment 3) and with a highly reliable drop in the case of free recall (Experiments 1 and 2). These memory decrements are accompanied by substantial slowing of the RT task, especially for free recall. In Moscovitch's (1992) terms, the strategic frontal component is involved to some extent in cued recall and to a greater extent in free recall; this involvement is signaled by the substantial RT costs observed at retrieval. It is noteworthy, however, that the memory decrements (even in free recall) are very much less than those seen at encoding; it appears that retrieval processes are in some sense obligatory, or are protected, with the result that attentional resources are demanded and redeployed for their execution.

We claim that these suggestions provide a plausible account of the complex but replicable pattern of results presented earlier, but many questions remain unanswered. The functions and characteristics of the retrieval mode remain obscure. Tulving (1983) suggested that retrieval mode constitutes a necessary condition for episodic retrieval, but to what extent does it enhance retrieval performance, is it all-or-none or graded, and does the retrieval mode for some paradigms (e.g., recall) require more attentional resources than for other paradigms (e.g., recognition)? A second set of questions concerns the observation that changes in emphasis at retrieval affect RT without affecting memory performance. Is the change in RT cost attributable to inefficient dual-task management, and if so, is the cost reduced by extended practice? Third, how does the proposed cue elaboration function at retrieval relate to stimulus elaboration at encoding? It is possible that one set of processes is responsible for both functions. If so, are the processes mediated or controlled in both phases of memory by the left dorsolateral prefrontal region of the cortex, as might be inferred from the involvement of that region in deeper types of verbal processing (Kapur et al., 1994; Raichle, 1994)?

Whatever the answers to these questions, our experiments have contributed a number of new and replicable findings to the study of dual-task processing, shed further light on the relations between encoding and retrieval processes, and suggested questions that may strengthen the links between cognitive and neuropsychological approaches to human memory.

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Appendix

Detailed Evaluation of the Shared Time Model

In all four experiments, statistical analyses of the differences between predicted and observed recall and recognition scores were based on individual curves calculated separately for each participant. For example, in Experiment 1, each participant had a recall score for each of the four presentation rates at encoding, and a best-fit exponential function was fitted to these four points. This function was then used to predict recall in the DA at encoding condition, on the basis of that participant's amount of slowing on the RT task. Predicted and observed scores were then evaluated by t test or ANOVA. For Experiment 1, the mean RT value for the DA at encoding condition was 462 ms, compared with 420 ms when the CRT task was performed alone. Following our logic, this means that 42 ms were available for memory encoding for each of the 130 responses (60 s/462 ms) in the 60-s encoding phase. That is, 5.45 s were available in total, equaling 0.36 s for each of the 15 words. When the value of 0.36 s is applied to the function shown in Figure 4A, the predicted recall value is 1.5 words, clearly very different from the observed recall value of 5.1 words. However, a second possibility is that participants can also use the mechanical motor time in each RT response for memory encoding; only the decision time is unavailable. The press rate value was 182 ms, and it was therefore assumed under this model that 0.182 s × 130 responses = 23.66 s were also available for encoding. Adding the original 5.45 s gives 29.11 s, or 1.94 s/word. When this value is entered on the function shown in Figure 4A, it predicts a recall value of 6.2 words, which is significantly higher than the observed value of 5.1 words, $t(31) = 3.37$, $p < .01$. At retrieval in Experiment 1, the straightforward calculation yielded a predicted value of 4.6 words, which is very different from the observed value of 8.2 words. However, when motor time is again added, the predicted value rises to 7.3 words, which still differs reliably from the observed value, $t(31) = 2.46$, $p < .05$.

No calibration curve data were collected in Experiment 2, but the observed results were compared with results predicted from the group data from Experiment 1. An ANOVA was then carried out on the predicted and observed values for each participant by entering his or her time saved measure into the calibration function). At encoding the ANOVA showed a marginal effect of predicted versus observed, $F(1, 31) = 3.48$, $p < .10$, $MSE = 7.01$, a significant effect of emphasis, $F(2, 62) = 16.28$, $p < .01$, $MSE = 1.27$, and a significant Emphasis × Predicted/Observed interaction, $F(2, 62) = 5.21$, $p < .01$, $MSE = 1.17$. The interaction term demonstrates that the observed values fall systematically below the predicted values as the RT task receives greater emphasis. Subsequent t tests showed that neither the memory condition nor the 50/50 condition were associated with reliable differences between predicted and observed ($t < 1.0$ in both cases), but that the RT emphasis condition did show such a difference, $t(31) = 3.28$, $p < .01$.

At retrieval, an ANOVA on the Experiment 2 values yielded no reliable difference between predicted and observed, $F(1, 31) = 2.13$, $p > .10$, $MSE = 6.30$, a significant effect of emphasis, $F(2, 62) = 3.49$, $p < .05$, $MSE = 1.02$, and no significant interaction, $F(2, 62) = 1.24$, $p > .10$, $MSE = 1.12$. The predicted and observed scores for Experiments 1 and 2 are shown in Figure 4.

For Experiment 3, differences between the predicted and "motor-time-added" values were assessed as before. For encoding, the ANOVA showed that the observed values were significantly lower than the predicted values, $F(1, 31) = 30.59$, $p < .01$, $MSE = 1.98$. There were also reliable effects of emphasis, $F(2, 62) = 23.32$, $p < .01$, $MSE = 0.89$, and of the interaction, $F(2, 62) = 14.04$, $p < .01$, $MSE = 0.88$. Subsequent t tests showed that the observed value did not differ from the predicted value in the case of memory emphasis, $t(31) = 1.36$, $p > .05$, but that the observed values were reliably lower than predicted values for 50/50 and RT emphasis, $t(31) = 4.45$ and 6.34, respectively (both $ps < .001$). In the case of retrieval, observed values were again higher than predicted values (Figure 5B). An ANOVA showed that this difference was reliable, $F(1, 31) = 23.03$, $p < .01$, $MSE = 2.86$. However, neither the effect of emphasis, $F(2, 62) = 1.52$, $p > .05$, $MSE = 0.64$, nor the interaction, $F < 1.0$, was reliable.

In the case of Experiment 4, the ANOVA for encoding showed that the observed values were reliably lower than the predicted values, $F(1, 23) = 4.28$, $p = .05$, $MSE = 238.2$. There was also a reliable effect of emphasis, $F(2, 46) = 4.43$, $p < .05$, $MSE = 107.6$, and a marginally reliable interaction, $F(2, 46) = 2.89$,

(Appendix continues on next page)

$p < .10$, $MSE = 105.7$. Subsequent t tests showed that the RT emphasis condition was reliably lower than prediction, $t(23) = 3.36$, $p < .01$, but that in the other two cases the predicted and observed values did not differ reliably, $t(23) = 1.13$ and 0.16 for 50/50 and RT, respectively. In the case of DA at retrieval, Figure 6B shows that the observed values are all close to the best fitting linear function. The ANOVA revealed no reliable effects (all F values < 1.0).

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