Memory & Cognition
2000, 28 (6), 965-976

Asymmetry between encoding and retrieval processes: Evidence from divided attention and a calibration analysis

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Two experiments provide further information on the effects of divided attention (DA) on encoding and retrieval processes. The first experiment examined the effects of decision and motor difficulty of a concurrent reaction time task. A calibration analysis was used in the second experiment to test the hypothesis that shifting attentional emphasis away from encoding to the secondary task reduces the level of processing the to-be-remembered items receive. Overall, the results confirm and extend the conclusions of Craik, Govoni, Naveh-Benjamin, and Anderson (1996) and Naveh-Benjamin, Craik, Guez, and Dori (1998), by pointing to clear differences between encoding and retrieval processes: Encoding is affected by simultaneous task demands, especially those associated with "central" resources involved in conscious decision making, whereas retrieval is obligatory in that it is largely immune to the effects of simultaneous demands. The results of the calibration analysis suggest that one reason for the poorer memory performance as a result of DA at encoding is a qualitative shift to less deep, elaborative strategies.

Much research on human memory suggests that the similarity between encoding and retrieval processes is an important factor in successful remembering. For example, the encoding specificity principle (Tulving, 1983), the transfer-appropriate processing view (Morris, Bransford, & Franks, 1977), and the proceduralist view of mind (Kolers, 1973) all claim that retrieval processes are involved in reinstating the same mental/neural operations that were active at encoding. In contrast, recent studies using the divided attention (DA) paradigm have shown marked differences between encoding and retrieval processes. When participants' attention is divided between encoding and a secondary task, memory performance is poor relative to when participants pay full attention to encoding the items (e.g., Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). The same effects of DA at encoding have been shown for a variety of memory features, including frequency of occurrence (Naveh-Benjamin & Jonides, 1986), spatial location (Naveh-Benjamin, 1987), and temporal order information (Naveh-Benjamin, 1990). Craik et al. (1996) further demonstrated that encoding words results in a reliable decrement to secondary task performance and that instructions to emphasize the memory task, the secondary task, or both tasks equally have complementary effects on the two tasks: As attention is shifted to the memory task and away from the secondary task, memory performance improves and secondary task performance declines. Taken together, these results suggest that encoding processes are consciously controlled and attention demanding.

Studies investigating the effects of a secondary task at retrieval have yielded different results, however. For example, Baddeley et al. (1984) and Craik et al. (1996) showed little, if any, reduction in free recall, cued recall, and recognition performance when attention was divided at retrieval. Craik et al. (1996) additionally demonstrated that the relative immunity of memory to DA at retrieval was accompanied by substantial secondary task costs, which decreased from free recall to cued recall to recognition. Finally, emphasis instructions had no effect on memory performance under DA at retrieval, even though secondary task performance was modulated by these instructions equally during encoding and retrieval. Craik et al. (1996) interpreted these effects as indicating that retrieval processes are obligatory, or protected, but that

This research was supported in part by the Faculty of Humanities and Social Sciences Extended Grant to the first author and in part by a grant from the Natural Sciences and Engineering Research Council of Canada to the second author. The authors thank Lianne Carley for her assistance. Correspondence should be addressed to M. Naveh-Benjamin, Department of Behavioral Sciences, Ben-Gurion University of the Negev, Beer-Sheva 84120, Israel (e-mail: naveh@bgumail.bgu.ac.il).

their execution requires substantial resources, as shown by the large secondary task costs.

As we have argued previously (Craik et al., 1996; Craik, Naveh-Benjamin, & Anderson, 1988; Naveh-Benjamin, Craik, Guez, & Dori, 1998), these observed differences between encoding and retrieval do not necessarily disagree with the theoretical positions and empirical findings that stress the similarities between the two sets of processes. Whereas previous work on encoding specificity, transfer-appropriate processing, and repetition of operations refers to the encoding and retrieval processes related to the actual representations themselves, our working assumption is that the encoding/retrieval differences demonstrated in our experiments relate to the different control processes associated with encoding and retrieval. This distinction between different control processes for episodic memory encoding and retrieval operations, yet similar operations concerned with access to the representations themselves at encoding and retrieval, is supported by recent findings using functional neuroimaging. The differential involvement of the left and right frontal lobes during encoding and retrieval respectively is now very well documented (see Cabeza & Nyberg, 1997, and Nyberg, Cabeza, & Tulving, 1996, for reviews), and this difference may be attributed to different control processes. On the other hand, there is also good evidence that initial perception/encoding and subsequent retrieval activate the same cortical areas (Mishkin & Appenzeller, 1987; Nyberg et al., 1995; Squire, Cohen, & Nadel, 1984; Wagner et al., 1998), and we interpret these latter findings as illustrating the necessary similarity between encoding and retrieval processes in terms of the initial establishment of, and later access to, the representations themselves.

The purpose of the present experiments was to shed further light on the nature of encoding processes in the context of attentional demands, especially to explore the reasons for their sensitivity to DA manipulations. If encoding processes involve conscious control (e.g., working memory), then only certain types of manipulations of the complexity of the secondary task—namely, those that involve more central information processing, or conscious decision making—should affect later memory performance. Murdock (1965) had participants sort cards into one, two, or four piles during encoding and showed that free recall performance declined as secondary task demands increased. However, the source of this effect is unclear, since the manipulation of number of piles to be sorted involves both a decision and a motor component. In addition, no appropriate continuous secondary task performance was reported. Finally, Murdock's study did not compare the effects of DA at encoding to those at retrieval.

To test our assertion—that only those manipulations of the complexity of the secondary task that involve more central information processing, or conscious decision making, should affect later memory performance—in the first experiment, we employed two manipulations of secondary task difficulty. One was related to decision difficulty, where the secondary task consisted of either a continuous three-choice or six-choice reaction time (RT) task. This manipulation reflects "cognitive-central resources" or conscious decision making (Hick, 1952; Welford, 1976). The other manipulation was related to the motor-response difficulty involved in the task, where the secondary task consisted of either a one- or two-press response. This manipulation requires less cognitive-central resources, since it involves mechanical motor processing.

These two manipulations have some advantages over the ones used by Craik et al. (1996). First, rather than imposing subjective demands by employing an emphasis manipulation (as done by Craik et al., 1996), these manipulations impose external-objective demands on participants' performance. Second, these manipulations involve graded demands on performance where a secondary task is performed in several conditions, but with different parameter values. This may allow one to disentangle the effects of a change in the amount of resources allotted to encoding or retrieval from those associated with the qualitative changes in behavior when single-task performance is compared with dual-task performance, as done in previous studies.

If encoding processes are controlled, as indicated by the previously described studies, we would expect poorer memory performance under DA at encoding than under full attention (FA). Furthermore, we would expect the manipulation of decision difficulty at encoding to have a detrimental effect on memory performance. That is, we would expect greater memory costs due to DA at encoding when the six-choice RT task is performed than when the three-choice RT task is performed. In contrast, manipulations of motor difficulty should not affect encoding processes, because such manipulations involve central decision making to a much lesser extent. As for retrieval processes, if they are obligatory, not under conscious control, and resistant to DA, as previous research indicates (Baddeley et al., 1984; Craik et al., 1996), then we would expect little or no difference in memory performance under DA conditions at retrieval relative to that under FA conditions. Furthermore, neither decision difficulty nor motor difficulty manipulations at retrieval should affect memory performance, although secondary task RT performance may well be slowed by increases in either central or motor difficulty.

A second possibility is that DA at encoding may change the qualitative nature of encoding achieved. For example, words may be encoded in a deep and elaborate fashion under FA but in a shallower and less effective manner when attention is divided. We raised this possibility earlier (see Craik et al., 1996, p. 174) to explain results from a calibration analysis. A calibration analysis allows one to express performance on both the memory and the secondary tasks in a common metric—the time taken by the tasks and their components. The expression of choice reaction time (CRT) performance in terms of time taken is straightforward: Task performance is measured in terms of RT per response, and a comparison between these times during single-task and dual-task processing gives a measure of the resources consumed by the primary task or by the need to manage two simultaneous tasks. Memory performance was converted into units of time via a conversion function. First, a function was constructed relating presentation time at encoding to recall performance, and then this function was used to predict the level of memory performance under DA conditions given the amount of time "provided" by the slowing of the CRT task (see the Appendix for details of the shared-time model).

We previously showed (Craik et al., 1996) that when attention is divided at encoding, memory performance falls short of the level predicted from the calibration function; moreover, the extent to which the calibration function overpredicts memory performance increases as participants shift their task emphasis from memory encoding to performing the secondary task. In contrast, when attention is divided at retrieval, memory performance is equal to or exceeds the level predicted from the calibration function. We suggested that, during retrieval, some degree of parallel processing is possible between memory retrieval and performance on the CRT task. In contrast, during encoding, there are several possibilities for the lower-than-expected memory levels. One is that the management of the division of attention at encoding itself requires attentional resources. Another possibility is that DA reduces the quality of encoding, particularly when participants' emphasis is on the secondary task.

This second possibility was the working hypothesis of Experiment 2. We constructed three functions relating presentation time at encoding to free recall performance, one each for deep semantic encoding, medium-level phonetic encoding, and shallow surface encoding. We expected that recall would increase as presentation time increased in all three cases but that the overall levels of recall would reflect the qualitative type of encoding utilized, with the highest level following semantic encoding and the lowest level following surface encoding. The three functions would therefore act as "cognitive contours" mapping out a space defining memory performance as a function of both encoding time and the qualitative nature of the encoding operations. If it is the case that DA shifts the type of encoding achieved from deeper to shallower, then recall under DA conditions should fall on points lower than those delineating the semantic function. Moreover, if the shift in subjective emphasis from the memory task to the CRT task implies a further shift in the qualitative nature of encoding toward shallower types of processing, then recall following emphasis on the memory task, the two tasks equally, and the CRT task should move progressively from the deeper to the shallower areas of the memory space. It is not possible to predict the exact location of recall values following the three different conditions of emphasis; however, if the results conform to the pattern described, it will provide support for the conclusion that shifts of emphasis from the memory task to the secondary task, as well as the DA manipulation itself, reduce recall performance because of shifts in the qualitative nature of the encoding operations engaged.

To address these questions, we employed a dual-task paradigm with the following features. First, we used a well-understood memory paradigm (cued recall) in which encoding and retrieval phases could be clearly separated. To avoid modality-specific interference, we presented the word lists auditorily and asked for spoken recall, whereas we used visual stimuli and manual responses in the concurrent task. The concurrent task was a continuous CRT task reported in our earlier study (Craik et al., 1996), in which the participant's response immediately caused the next stimulus to appear. Since performance did not reach ceiling on either task performed singly, we argue that each task required full attention to perform on its own. When performed together, the tasks allowed for assessment of performance throughout the dual-task interval. Finally, in Experiment 2, we attempted to provide a common metric for the memory and CRT tasks in terms of time utilized in order to assess qualitative changes in encoding under DA.

EXPERIMENT 1

The purpose of Experiment 1 was to assess the effects of manipulating the difficulty of the secondary task on memory performance and on the attentional costs of encoding and retrieval in a cued recall paradigm. We manipulated decision difficulty of the secondary task by asking participants to respond to either a three-choice or a six-choice RT task, and we manipulated the motor difficulty of the secondary task by asking participants to press each key either once or twice for a given response. The CRT task was performed alone and concurrently with either the encoding or the recall phase of the memory task; attentional costs were indexed by the increase in RT from single- to dual-task conditions. Cued recall was also measured under FA conditions, and so the effects on memory of DA at encoding and retrieval could be assessed.

Method

Participants. Twenty-four 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 432 two-, three-, and four-syllable common nouns, allocated randomly into 18 lists of 12 unrelated word pairs. The lists were recorded on an audiotape recorder at the rate of 6 sec per pair. Ninety-six additional words were used in the practice session.

Experimental tasks. The memory task consisted of the presentation of one of the paired-associate lists, followed immediately by an arithmetic task to eliminate recency. In the arithmetic task, the participants heard a sequence of 20 random digits (1–9) presented auditorily at a 1-sec rate; the participants were instructed to add 3 to each number and speak their responses. This task was immediately followed by the memory retrieval phase, in which the first word of each pair was presented as a cue, auditorily, at a 6-sec rate, and in a different random order from the presentation order. The participants attempted to recall the word that had been paired with each cue during the study phase; their oral responses were tape-recorded for later transcription. In summary, the memory task was cued recall, with a 72-sec encoding phase (12 word pairs × 6 sec), an interpolated arithmetic task, and a 72-sec recall phase.

The CRT task involved a visual display on a computer screen and manual responses on an external button box. The display consisted of either three or six boxes, arranged horizontally. A large white rectangle appeared at random in one of the boxes, and the participant's task was to press the corresponding key on the external button box. The response caused the white rectangle to move immediately to one of the other boxes, at random; the rectangle never appeared in the same box on successive CRT trials. The goal was to carry out the task as quickly and accurately as possible. The task was thus a continuous CRT task; it was performed for 72 sec (alone and during either the encoding or the retrieval phase).

The participants performed the CRT task by pressing the appropriate key either once (one-press condition) or twice successively (two-press condition). The accuracy and speed of the participants' responses (in milliseconds) were recorded by the computer. In the two-press condition, RTs were recorded from the second keypress. The CRT task was performed either alone or in combination with the encoding or retrieval phase of the cued recall task; there were no trials in which the CRT task was carried out during both encoding and retrieval in this experiment.

Procedure and Design. The participants performed the CRT task alone eight times for 72 sec each, for two replications of each of the combinations of decision difficulty (three vs. six choices) and number of presses (one vs. two). The memory task was also performed alone (i.e., under FA conditions) for two trials, and the four combinations of the CRT task were performed twice concurrently with encoding or with retrieval (i.e., under DA conditions) for a total of 16 trials. Before each DA trial, the participants were informed whether the CRT task would be performed during the encoding or the retrieval phase. Additionally, the participants were told before each trial whether to respond with one or two presses and whether three or six boxes would appear on the screen. The 16 DA trials were thus made up of two replications of the 2 × 2 × 2 combinations of decision difficulty (three or six choices) and motor difficulty (one or two presses) either at encoding or at retrieval. All variables were manipulated within subjects.

The participants were first given a description of the tasks in the experiment, followed by practice on each task. First, the CRT task was practiced for two trials of 30 sec, then the interpolated arithmetic task was practiced for two trials. The memory task was then administered; 12 word pairs were presented auditorily at a rate of 6 sec per word followed by the arithmetic task, followed by spoken recall for 72 sec (12 words for 6 sec each). In the FA practice trial, the participants were told to pay attention to the words in order to memorize them as best they could. In the two DA practice trials, the participants were told to split their attention equally between the CRT and the memory task at either encoding or retrieval.

After these practice trials, the experimental trials were presented. All participants heard the 18 lists in the same order, but the order of the task conditions applied to each list were counterbalanced. In all, 12 formats were used; the three attention conditions (FA, DA at encoding, and DA at retrieval) were presented in an order governed by a Latin Square design, yielding three different orders. For both the DA-at-encoding task and the DA-at-retrieval task, the four orders of the sequence of number of choices (three or six) and number of presses (one or two) were determined by a Latin Square design. Thus, in total there were 12 unique orders of attention condition and CRT difficulty. One order was assigned to each of 12 participants, and the tasks were run in one order in the first session and in the opposite order in the second session, which took place 1 or 2 days after the first session. The other 12 participants were run in the opposite order. Two replications of all combinations of the CRT task were dispersed among the memory tasks in a random order, half in the first session and half in the second session. Altogether, the participants performed 13 experimental trials in each session (4 CRT trials, 1 FA memory trial, 4 DA-at-encoding trials, and 4 DA-at-retrieval trials), with 1 or 2 min between each trial in order to introduce the next trial. Each session took about 90 min.

Results

Memory performance. Table 1 shows the number of correctly recalled words (out of 12) for each condition. The participants recalled 8.02 words on average in the FA condition. The recall level dropped by 8% in the DA-at-retrieval conditions ($M = 7.40$) and by 26% in the DA-at-encoding conditions ($M = 5.90$). A t test contrasting free recall performance under FA and DA at retrieval showed that the drop was not reliable [$t(23) = 1.67, p > .10$]. A similar test contrasting FA with DA at encoding showed a reliable effect [$t(23) = 7.31, p < .001$].

A 2 × 2 × 2 within-subjects analysis of variance (ANOVA) on the DA conditions, with locus of attention (DA at encoding and DA at retrieval), decision difficulty (three vs. six choices), and motor difficulty (one vs. two presses) as the variables, revealed that performance was better under DA at retrieval than under DA at encoding [$F(1,23) = 20.90$, $MS_e = 5.20$, $p < .01$], performance was better under the three-choice condition than under the six-choice condition [$F(1,23) = 9.55$, $MS_e = 1.08$, $p < .01$], and a significant interaction of locus of attention with decision difficulty [$F(1,23) = 8.50$, $MS_e = 1.01$, $p < .01$]. Further comparisons indicated that the source of this interaction was the significant effect of de-

Table 1
Mean Number of Correctly Recalled Words and Standard Deviation for Each Divided Attention (DA) Condition as a Function of Decision Difficulty (Three Choice vs. Six Choice) and Motor Difficulty (One Press Vs. Two Presses) of the Secondary Task in Experiment 1

	Three Choice				Six Choice			
	One Press		Two Presses		One Press		Two Presses	
Attention Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
DA at encoding	6.21	2.63	6.48	2.50	5.50	2.61	5.42	2.82
DA at retrieval	7.58	2.69	7.27	2.49	7.50	2.63	7.27	3.02

Note—Number of words recalled in the full attention condition = 8.02 (2.26). Maximum = 12.

Table 2
Mean Choice Reaction Time (in Milliseconds) and Standard Deviation for Each Attention Condition as a Function of Decision Difficulty (Three Choice vs. Six Choice) and Motor Difficulty (One Press vs. Two Presses) of the Secondary Task in Experiment 1

	Three Choice				Six Choice			
	One Press		Two Presses		One Press		Two Presses	
Attention Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Full attention	361	33	566	63	447	49	636	77
DA at encoding	377	42	595	57	462	61	682	88
DA at retrieval	390	57	622	79	492	74	705	104

cision difficulty at encoding (three-choice $M = 6.35$, and six-choice $M = 5.46$; $p < .01$) and the lack of effect of decision difficulty at retrieval (three-choice $M = 7.42$, and six-choice $M = 7.39$; n.s.). No other effects were significant ($F < 1.0$).

Secondary task performance. Table 2 shows CRT (in milliseconds) for each condition. The participants' average CRT in the baseline condition was 502 msec and became slower when performed during encoding (529 msec) and during retrieval (553 msec). CRT performance was reliably faster when performed alone than when performed during encoding [$t(23) = 2.86$, $p < .01$] or retrieval [$t(23) = 3.26$, $p < .01$]. A $3 \times 2 \times 2$ within-subjects ANOVA, with attention condition (CRT alone, DA at encoding, and DA at retrieval), decision difficulty (three vs. six choices), and motor difficulty (one vs. two presses) as variables, yielded a significant effect of attention [$F(2,46) = 9.09$, $MS_e = 6.60$, $p < .01$], slower performance in the six-choice condition ($M = 573$) than in the three-choice condition ($M = 485$) [$F(1,23) = 202$, $MS_e = 2.52$, $p < .01$], and slower performance in the two-press condition ($M = 636$) than in the one-press condition ($M = 420$) [$F(1,23) = 409.07$, $MS_e = 7.86$, $p < .01$]. Finally, there was a significant interaction of attention condition and motor difficulty [$F(1,46) = 6.72$, $MS_e = 6.25$, $p < .05$]. Further comparisons indicated that the source of this interaction was the larger effect of motor difficulty in the two DA conditions (one-press $M = 430$, and two-press $M = 651$) than in the baseline condition (one-press $M = 403$, and two-press $M = 600$). No other effects were significant.

In order to assess secondary task costs directly at encoding and at retrieval, the appropriate baselines (performance on the secondary task alone) were subtracted from each CRT performance in each of the DA conditions. The results are shown in Table 3. A $2 \times 2 \times 2$ within-subjects ANOVA was conducted on these data, with attention condition (DA at encoding vs. DA at retrieval), decision difficulty (three vs. six choices), and motor difficulty (one vs. two presses) as variables. Secondary task costs were larger during retrieval ($M = 50$ msec) than during encoding ($M = 27$ msec) [$F(1,23) = 6.45$, $MS_e = 50.0$, $p < .05$], larger in the six-choice condition ($M = 44$ msec) than in the three-choice condition ($M = 32$ msec) [$F(1,23) = 4.39$, $MS_e = 10.0$, $p < .05$], and larger in the two-press condition ($M = 50$ msec) than in the one-press condition ($M = 26$ msec) [$F(1,23) = 8.94$, $MS_e = 30.0$, $p < .01$]. None of the interactions were significant.

Discussion

The results of Experiment 1 indicate that manipulating the difficulty of a secondary task affects encoding and retrieval processes differently. More specifically, when the decision component of the secondary task is more complex (in terms of information uncertainty) during encoding, it damages later memory performance, whereas the same manipulation at retrieval has no effect on later memory performance. In contrast, when the motor component of the secondary task becomes more difficult (in terms of the motor-action components involved), it has no effect on subsequent memory performance during either encoding or retrieval.

Our conclusions are, first, that DA at retrieval has only a slight (and, in this case, nonsignificant) effect on cued recall, and, second, that the effects of DA at encoding on later cued recall depend on the nature of the secondary task—increases in decision difficulty reduce recall but increases in motor difficulty have no effect. The first con-

Table 3
Mean Choice Reaction Time (in Milliseconds) and Standard Deviation for Each Divided Attention (DA) Condition as a Function of Decision Difficulty (Three Choice Vs. Six Choice) and Motor Difficulty (One Press vs. Two Presses) of the Secondary Task After Subtracting the Appropriate Full Attention Baseline in Experiment 1

	Three Choice				Six Choice			
	One Press		Two Presses		One Press		Two Presses	
Attention Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
DA at encoding	16	41	29	51	15	31	46	68
DA at retrieval	29	59	56	77	45	79	70	100

clusion is in general agreement with the results of Kellogg, Cocklin, and Bourne (1982), Baddeley et al. (1984), and Craik et al. (1996). In the Craik et al. (1996) study, DA at retrieval did reduce cued recall significantly, but the magnitude of the effect was very similar (9% in Craik et al., 1996, and 8% in the present experiment). It seems reasonable to conclude that a visuomotor CRT task has a relatively small detrimental effect on cued recall when employed as a secondary DA task at retrieval but that memory losses may be greater if the memory task and the competing secondary task are qualitatively similar (cf. Fernandes & Moscovitch, 2000). It is also worth noting that memory losses owing to DA at retrieval apparently depend on the paradigm; in the Craik et al. (1996) study, the average loss was 12% for free recall, 9% for cued recall, and 1% for recognition.

In contrast to these relatively small effects of DA at retrieval, DA at encoding is associated with substantially larger effects. In the present experiment, the memory costs were 21% for the three-choice conditions and 32% for the six-choice conditions. This greater effect of DA at encoding than at retrieval replicates the findings of Craik et al. (1996), where the memory costs for cued recall were 33% and 9% for encoding and retrieval, respectively. The present experiment adds the further information that only certain types of DA task affect encoding— namely, tasks that consume central decision-making resources or (put another way) tasks that involve the central executive functions of working memory.

It might be objected that the shift from one-press to two-press CRT conditions did not represent any real increase in difficulty but simply resulted in longer RTs. Our response is that two-press RTs certainly take longer to accomplish but that this increase is also shown by the corresponding baseline conditions in which the CRT task was performed by itself. The crucial data are the secondary task cost data shown in Table 3. The shift from one-press to two-press conditions resulted in a significant increase in secondary task costs, as demonstrated by the previously quoted ANOVA. In fact, the average increase in RT costs from one-press to two-press was actually larger than the average increase in costs from three-choice to six-choice [24 and 12 msec, respectively; $t(23) = 1.97, p < .05$]. Thus, we argue that our manipulation of motor difficulty was effective but that this increased tax on attentional resources had no effect on the concurrent memory task at either encoding or retrieval.

One final result worthy of comment is that, in the present experiment, CRT costs were significantly larger at retrieval than at encoding, whereas in the Craik et al. (1996) study, RT costs were equivalent for encoding and retrieval. There are several possible reasons for this discrepancy (e.g., differences in materials and/or participants), but the most plausible is that RT costs reflect the attentional resources required to manage simultaneous memory and CRT operations and that retrieval is more sensitive than encoding to an increase in the complexity of these joint processing operations. The Craik et al. (1996) study showed that RT costs at retrieval varied substantially as a function of the paradigm used; average costs were 135 msec per keypress for free recall, 68 msec for cued recall, and 32 msec for recognition. That is, costs increased as the need for "self-initiated activities" increased (Craik, 1983). The present experiment used cued recall only but complicated the CRT task by incorporating decision and motor difficulty manipulations. Table 3 shows that the difference between encoding and retrieval costs was smallest (13 msec) for the simplest CRT condition (three-choice with one-press), the condition that was most similar to that used by Craik et al. (1996); the average difference between encoding and retrieval costs was 27 msec for the remaining conditions. Thus, our conjecture is that RT costs for DA at retrieval were relatively large in the present experiment because of the combination of a moderately demanding retrieval paradigm with relatively demanding CRT conditions.

Overall, the results of Experiment 1 confirm and extend the conclusions of Craik et al. (1996) and Naveh-Benjamin et al. (1998)—namely, there are some clear differences between encoding and retrieval processes. Whereas memory performance is affected by secondary task demands at encoding, although only when these demands are associated with central resources required for conscious decision making, memory is not affected by these same variations in secondary task demands at retrieval. The suggestion is therefore that encoding processes involve the central executive (or require attentional resources), whereas retrieval processes appear to be largely immune to variations in secondary task demands. On the other hand, secondary task costs are sensitive to variations in the demands of both the memory task and the secondary task itself (Craik et al., 1996), and the present results suggest that RT costs may be particularly sensitive to variations in retrieval difficulty.

EXPERIMENT 2

The purpose of Experiment 2 was to assess whether DA at encoding changes the qualitative type of encoding achieved. To achieve this aim, we used the calibration analysis described in the introduction and in the Appendix to determine the cause of the discrepancy between the results of obtained and predicted memory scores reported by Craik et al. (1996). As described in the introduction, these results indicated worse memory performance under conditions of DA at encoding than the memory levels predicted by the calibration functions. Furthermore, the deviation between predicted and observed memory performance became more pronounced when participants shifted their attention away from the memory task and to the secondary task. We wished to evaluate whether this discrepancy was due to qualitatively different encoding operations performed by the participants under the different emphasis instructions. That is, we hypothesized that, as the instructions change from emphasis on the memory task to emphasis on the two tasks equally and then to emphasis on the CRT task, processing resources become increasingly devoted to the secondary task; this forces a qualitative change to shallower encoding. In other words, participants can process the words to a deep semantic level in the memory emphasis condition, to a shallower level in the 50/50 emphasis condition, and to a yet shallower level in the CRT emphasis condition.

Testing this hypothesis involved generating separate calibration functions relating encoding time to recall performance, separately for each of three levels of processing: deep, medium, and shallow. This was done by having participants encode several paired-associate lists, presented at four different rates. It was expected that the calibration functions for the deep, medium, and shallow levels of processing would map out a set of cognitive contours relating encoding time and encoding type to later memory performance. It was, of course, unlikely that performance levels in the three emphasis conditions would correspond exactly to the levels marked out by the deep, medium, and shallow calibration functions. But, if encoding shifts from deep to shallow processing as attention shifts from the memory task to the CRT task, it was expected that memory performance following memory, 50/50, and RT emphasis instructions would shift progressively from deeper to shallower areas of the map delineated by the calibration functions (see the Appendix for a detailed example).

Method

Participants. The participants were 24 University of Toronto undergraduates who took part in the study for course credit.

Stimuli. The stimuli were 480 one-, two-, and three-syllable concrete nouns that were randomly arranged to form 24 lists of 10 unrelated word pairs each. All lists were presented auditorily via a tape player.

Experimental tasks. The memory task for the calibration part of the study consisted of the auditory presentation of 10 word pairs under FA conditions at rates of 2, 3, 4, or 6 sec per pair, depending on the list. Twelve such lists were presented, with each of the four presentation rates presented once under each of the three levels of processing. To induce a shallow level of processing, the participants were asked to judge which of the two words would come before the other if they were arranged alphabetically. A medium level of processing was induced by asking the participants to specify whether the two words had many, some, or no phonemes in common. The deep level of processing was induced by having the participants judge the strength of the semantic association between the words in each pair. The participants responded manually by circling their answers on a standardized response sheet. The encoding phase was followed by the 30-sec arithmetic task used in Experiment 1 and then by a cued recall test in which the first word of each pair was presented in a random order at a rate of 6 sec per cue, to which the participants responded orally.

The memory task for the DA part of the experiment consisted of two replications of one FA and three DA at encoding trials. All paired-associate lists consisted of 10 word pairs presented at a 6-sec rate, followed by the 30-sec arithmetic task, and then the cued recall task presented at a 6-sec rate. The DA trials were carried out under three different emphasis conditions. Prior to each of the six DA lists, the participants were instructed to focus their attention on either the memory task (while continuing to perform the CRT task as rapidly as possible) or the CRT task (while continuing to encode the presented list as best they could) or were instructed to divide their attention equally between the two tasks. These three different emphasis conditions are referred to as *memory*, *CRT*, and *50/50*, respectively.

The CRT task was the same as in Experiment 1, except that four boxes were used. The CRT task was presented alone three times for 60 sec and during encoding for the DA trials. Finally, a "press-rate" task was used in order to estimate the motor component of the CRT task. The participants were presented with the same four-box visual display as in the CRT task, but, in this case, the large white rectangle was displayed continuously for 6 sec in each box sequentially from left to right. The participants pressed the key corresponding to the box with the large white rectangle as often and as rapidly as possible during the 6-sec interval and then pressed the next key with the next finger as often and as rapidly as possible until all four boxes were displayed in three sequences for a total of 72 sec.

Procedure and Design. To prevent fatigue, the calibration and DA parts of the experiment were carried out in separate sessions, each lasting about 1 h. Prior to each of the two sessions, the participants performed a number of practice trials in order to familiarize themselves with the procedure. In the calibration part, the participants were presented with three paired-associate practice lists, one at a slow rate (6 sec), one at a medium rate (4 sec), and one at a fast rate (2 sec). The participants were also induced to process each list at shallow, medium, or deep level, as described above. In the DA part, they received the CRT task alone for 30 sec and were presented with one practice paired-associate list accompanied by the CRT task. No emphasis instructions were given for this practice list.

For the experimental trials, two presentation formats were used, and half of the participants received each format. Different orders of list presentation were used in each format, and different words were assigned to different lists in each format. Within each format, half of the participants performed the DA part in the first session and the calibration part in the second session; the other half of the participants performed the two parts in the reverse order.

The participants were told that the calibration part of the study was to find out how performing various judgments on word pairs would affect retention of the list. Two different orders of level of processing and presentation rate were created, one for each format; within each format, levels of processing conditions were presented in a blocked fashion, with presentation rate semi-counterbalanced (e.g., for Format B, the order of level of processing and presentation rate was medium [2, 4, 3, 6 sec], shallow [6, 3, 4, 2 sec], deep [4, 2, 6, 3 sec]). In the DA part of the experiment, all participants performed the CRT task alone for 60 sec three times: at the beginning, middle, and end of this part of the experiment. The press-rate task was performed twice: at the beginning and end of the session. Two orders of task emphasis (memory, 50/50, and CRT) were created, one for each format. For both calibration and DA sessions, the trials were separated by 1 or 2 min, during which the instructions for the next trial were provided. Each participant participated in all conditions; hence, in this experiment, we employed a within-subjects design.

Results

Divided attention at encoding. Figure 1A presents recall performance as a function of the attention condition and emphasis instructions. It may be seen that the average performance in the DA-at-encoding conditions (M = 4.72) was lower than in the FA condition (M = 7.08) [$t(23) = 6.88$, $p < .01$]. In addition, recall performance decreased as the emphasis shifted from memory, through 50/50 to CRT. Multiple t tests using the Bonferroni correction method were carried out to compare each of the

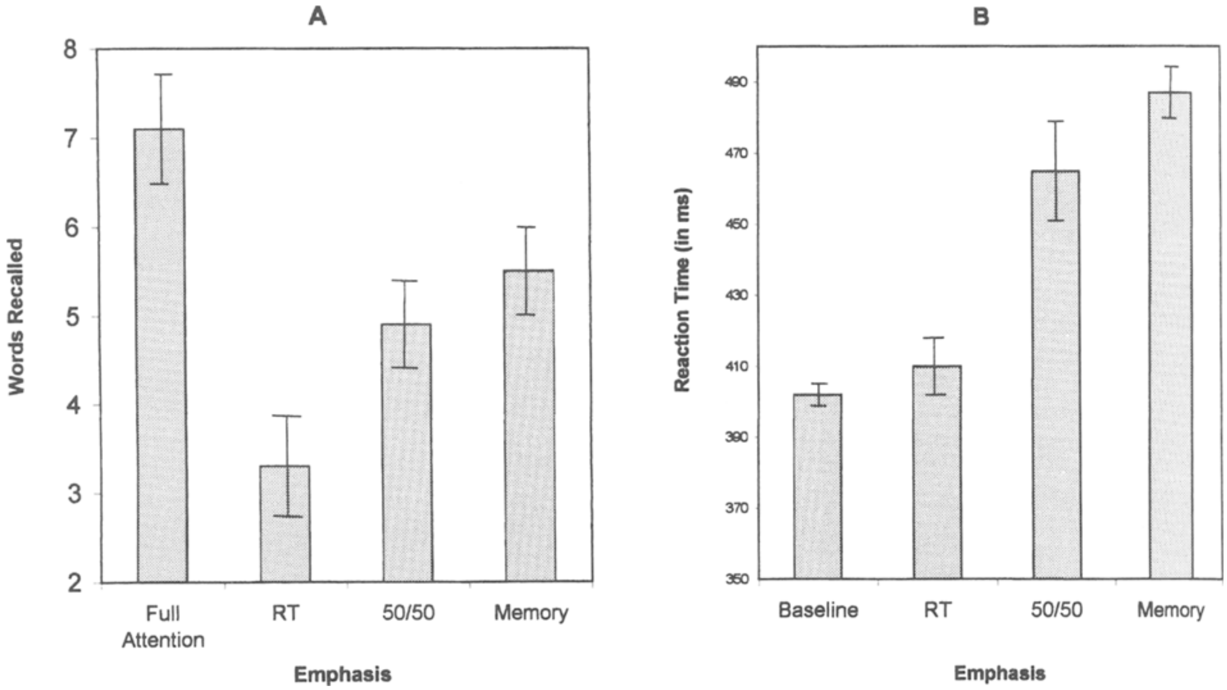

Figure 1. Average number of words recalled (A) and mean secondary CRT task performance (B) (±*SE*) under conditions of full attention and divided attention at encoding with memory, 50/50, and CRT emphasis in Experiment 2.

DA conditions with the FA condition. All three t tests showed a significant drop from FA to DA [$t(23) = 5.57$, $p < .001$, for the memory emphasis; $t(23) = 5.60$, $p < .001$, for the 50/50 emphasis; and $t(23) = 7.70$, $p < .001$, for the CRT emphasis]. A within-subjects ANOVA on the three DA conditions showed the effects of emphasis instructions to be significant [$F(2,46) = 12.93$, $MS_e = 1.40$, $p < .001$]. Newman–Keuls post hoc analysis showed that while recall performance was significantly lower in the CRT emphasis condition than in the 50/50 emphasis condition ($p < .05$) and in the memory emphasis condition ($p < .05$), the difference between the latter two did not reach statistical significance.

Figure 1B presents RT on the secondary task as a function of attention condition and emphasis instructions. RTs under DA at encoding conditions were slower than when the task was performed alone (average RTs for DA and FA were 451 and 403 msec, respectively) [$t(23) = 3.20$, $p < .05$]. In addition, CRT performance slowed as the emphasis shifted from RT, through 50/50 to memory. Multiple t tests using the Bonferroni correction method showed a significant increase in RT from FA to DA for the memory [$t(23) = 6.75$, $p < .001$] and for the 50/50 emphasis condition [$t(23) = 6.94$, $p < .001$] and a marginally significant increase for the CRT emphasis condition [$t(23) = 1.91$, $p < .06$]. A within-subjects ANOVA on the DA conditions showed a significant effect of emphasis instructions on RT performance [$F(2,46) = 37.50$, $MS_e = 947.6$, $p < .001$]. A Newman–Keuls post hoc analysis revealed that CRT performances in all three emphasis conditions were significantly different from each other ($p < .05$).

These results replicate those reported by Craik et al. (1996) and Naveh-Benjamin et al. (1998), showing that DA at encoding reduces memory performance significantly and that instructions to vary attentional allocation

Table 4
Mean Number of Words Recalled and Standard Deviation as a Function of Encoding Time and Level of Processing in Experiment 2

	Encoding Time (in sec)							
	2		3		4		6	
Level of Processing	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Deep	3.96	1.99	5.58	2.17	6.42	1.59	6.42	2.06
Medium	1.17	1.20	2.33	1.63	2.54	2.02	2.33	1.81
Shallow	0.33	0.56	0.83	1.05	1.83	1.76	1.96	1.97

Note—Maximum = 10.

between encoding and the secondary task affect memory performance significantly. The results also replicate CRT secondary task performance at encoding, indicating an increase in CRT from single-task performance and an effect of task emphasis on CRT.

Calibration functions. The mean recall scores for the three levels of processing at each presentation rate appear in Table 4. The table illustrates the general trend of improvement in memory performance as a function of the time available for the encoding of each pair, with performance leveling off beyond the 4-sec rate. The table also shows that, across all four presentation rates, the level of processing manipulation affected memory in the expected manner: Performance was best under the deep level of processing and worst under the shallow level. A two-way ANOVA involving level of processing and presentation rate indicated a significant effect of presentation rate [$F(3,69) = 20.03$, $MS_e = 2.49$, $p < .05$], a significant effect of level of processing [$F(2,46) = 176.56$, $MS_e = 2.89$, $p < .01$], and no significant interaction of the two [$F(6,138) = 2.16$, $MS_e = 1.52$, $p > .10$].

We applied the best-fitting function to each of the three levels of processing data points. Although an exponential function provided the best fit to the data using the four rates of presentation, we decided to fit a function to the three faster rates of presentation only (2, 3, and 4 sec per word). The reason for this was that all of the calculated encoding times (described below) were between 2 and 4 sec, and, as a result, the predictor points would be found within this interval. With three presentation rates, a linear function provided the best fit.

Encoding time was calculated as described in the Appendix. By following these steps, we determined that there were 3.96, 3.87, and 3.61 sec functionally available for encoding each item in the memory, 50/50, and RT emphasis lists, respectively. The predicted recall values for each of the three emphasis conditions were then determined by entering the obtained times into the calibration functions. Figure 2 shows the calibration functions for the deep, medium, and shallow levels of processing, as well as the observed recall values for the memory, 50/50, and CRT emphasis conditions. The figure shows that, as emphasis in the DA conditions shifts from memory encoding to the RT task, the subsequent levels of memory performance fall from those achieved with the deep calibration function toward the levels shown by the medium calibration function. Specifically, memory performance following DA at encoding lies between the level achieved with semantic processing and a 4-sec rate and the level associated with phonemic processing and a 3-sec rate. That is, the effects of a shift of emphasis from memory to the RT task mimic the effects associated with a slight restriction in encoding time plus a qualitative change in type of encoding from semantic to phonemic processing. The

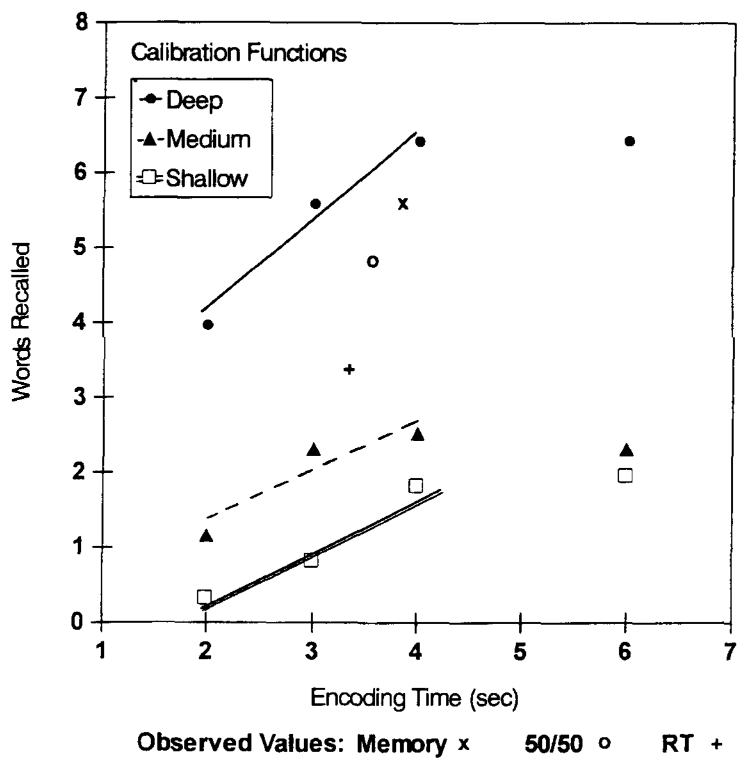

Figure 2. Cued recall calibration functions (for 2, 3, and 4 sec), plotting words recalled as a function of the time available and the level of processing at encoding in Experiment 2. Observed recall values as a function of emphasis condition are also shown. See text for further details.

pattern of results closely replicates the pattern found with cued recall in our previous work (Craik et al., 1996, Figure 5).

Discussion

The results of Experiment 2 confirm previous results (Craik et al., 1996) in many respects. First, the results show that DA at encoding leads to a significant decrease in memory performance relative to encoding under FA. Second, memory was sensitive to changes in emphasis instructions during the encoding phase. The results of Experiment 2 show that recall performance became progressively worse as emphasis instructions shifted from memory to CRT; the participants performed best when instructed to focus on the memory task, worst when instructed to focus on the CRT task, and in between when instructed to focus equally on the memory and the CRT tasks. Third, DA at encoding also had a negative effect on secondary task performance, which was most disrupted under the memory emphasis condition, less disrupted under the 50/50 emphasis condition, and least disrupted under the CRT emphasis condition. These results closely replicate those of Craik et al. (1996) in demonstrating a tradeoff between the memory task and the secondary task during encoding.

The primary purpose of this experiment was to determine whether the departure from the predicted calibration curve observed by Craik et al. (1996), especially as emphasis shifted to the RT task, was due to the fact that when the participants had to devote more attention to the secondary task, their encoding of the material became shallower. Inspection of Figure 2, which presents the predicted performance using the calibration functions created for the different levels of processing, along with the observed performance in the three emphasis conditions, shows that, at least qualitatively, the results confirm the hypothesis raised: As emphasis shifted from the memory task to the RT task, the observed recall values departed progressively from the values predicted by the deep calibration function. Such a pattern indicates that, as emphasis is shifted away from the memory task, participants' performance increasingly deviates from the one to be expected if participants encoded the information at a deep level of processing and approaches the level expected if participants encoded the words in a phonemic manner. It therefore appears that the shared time model proposed by Craik et al. (1996) must be modified to take type of processing into account, as well as the functional time available. Our claim is that the "cognitive contours" mapped out by the three calibration curves describe the relations between encoding time and type of processing, on the one hand, and subsequent memory performance, on the other. The point that this progressive change in encoding represents a shift from deep to shallow processing is certainly supported by the results shown in Figure 2, although, admittedly, the present encoding map may not be the only possible version. A more precise specification of the qualitative types of encoding achieved under dual-task conditions will require converging evidence from other experimental manipulations.

GENERAL DISCUSSION

The results of the two experiments confirm and extend the conclusions reached by Craik et al. (1996) and Naveh-Benjamin et al. (1998) by indicating that, despite a tradition in cognitive psychology that views encoding and retrieval processes as being similar, these processes also differ in important ways. Specifically, encoding processes are significantly affected by simultaneous processing demands, whereas retrieval processes are much less affected. In both experiments, recall under DA at encoding dropped by 26%–33% relative to recall under FA at encoding. In contrast, recall performance under DA at retrieval dropped by only 8% (Experiment 1)—a decline that was not statistically reliable.

Furthermore, the results of Experiment 1 indicate that manipulating the difficulty of the secondary task differentially affects encoding and retrieval processes. The difficulty of the decision component of the secondary task affected encoding but not retrieval; the more complex this decision component was during encoding (in terms of information uncertainty), the more it damaged later memory performance. In contrast, such a manipulation at retrieval had no effect on memory performance. In Experiment 2, encoding was also affected by instructions to vary task emphasis between encoding and the secondary task. Memory performance declined and CRT performance improved as the instructions at encoding assigned higher priority to the CRT task. Finally, Experiment 1 showed that encoding (like retrieval) seems to be unaffected by the difficulty of a simultaneous activity that does not require central resources; when the motoric component of the secondary task was made more difficult (in terms of motor-action components involved), during either encoding or retrieval, subsequent memory performance was not affected. This pattern of results is compatible with the view that encoding processes require central resources and are under the participant's control. This view is further supported by the results of Experiment 2: As instructions moved the participants' processing emphasis progressively away from memory encoding to fast performance of the CRT task, subsequent memory performance dropped in a pattern compatible with the notion that both processing time and processing depth were progressively restricted.

Retrieval, on the other hand, seems to differ from encoding in that it was affected neither by the introduction of a secondary task nor by the manipulation of the decision complexity of the secondary task (Experiment 1). These results may lead one to think of retrieval as being automatic, but there are several indications that this is not the case. First, Experiment 1 showed that retrieval does require attention. The participants performed more slowly on the CRT task during retrieval than when it was performed alone. In addition, RTs during retrieval were sensitive to the level of decision complexity required by the secondary task, but retrieval itself was not affected by secondary task complexity. Both of these results indicate that retrieval is resource demanding. The picture emerging from these results for retrieval is that it is obligatory or autonomous in that it is only marginally interrupted by other activity, yet it draws resources for its completion, resulting in the slowing down of performance on the concurrent task.

The lack of an effect of motor difficulty on memory performance, either at encoding or at retrieval, indicates that neither the covert motor encoding activity (e.g., rehearsal) nor the overt motor retrieval activity (retrieving aloud) is significantly affected by the motoric demands of the concurrent task. The results do indicate, however, that the manipulation was successful: DA costs were significantly greater for the difficult motor task (two presses) than for the easy version (one press). In addition, despite the fact that the increase in motor difficulty had no effect on either encoding or retrieval, the increase in DA costs from one press to two presses was significantly greater than the increase in DA costs associated with the shift from three-choice to six-choice decisions.

Is it possible that the observed asymmetry between the effects of DA at encoding and at retrieval stems, at least in part, from different tradeoff strategies adopted by the participants at encoding and at retrieval? The participants may have given priority to the RT task at encoding and to the memory task at retrieval. Also, the consequences of paying more or less attention to encoding operations are not felt until a later time, as opposed to the immediate sense of success or failure at retrieval. We believe that the asymmetry reflects fundamental differences between encoding and retrieval rather than a simple difference in attentional allocation policy. First, in Experiment 1 in Naveh-Benjamin et al. (1998) and in Experiments 3 and 4 in Craik et al. (1996), all of which employed cued recall or recognition memory tasks, the secondary task costs were the same at encoding and retrieval, yet DA had a much greater effect on encoding. Second, in Experiments 2–4 in Craik et al. (1996), shifting participants' priorities from retrieval to the secondary task improved performance in the secondary task but had no effect on memory performance. When performed at encoding, such a shift of emphasis reduced memory performance under DA even further. The same pattern of shifting priorities at retrieval having no effect on memory performance was recently obtained by Anderson, Craik, and Naveh-Benjamin (1998, Experiments 2 and 4) for both young and older adults.

One puzzling result obtained by Craik et al. (1996) was that the observed recall values following DA at encoding fell below the predicted values derived from calibration functions. In addition, the observed values fell further below the predicted values as emphasis instructions shifted attention from the memory encoding task to the concurrent RT task. In the present Experiment 2, we investigated the possibility that this systematic deviation was a consequence of shallower levels of encoding associated with less attention devoted to the encoding task. Figure 2 shows that the observed values of memory performance in three emphasis conditions fell between the calibration functions associated with semantic and phonemic processing in FA conditions. That is, as attention shifted from the memory encoding task to the CRT task under DA conditions, the type of encoding achieved apparently changed from deeper to shallower. Thus, although the observed values for the three emphasis conditions did not fall on the "predicted" calibration curves, the pattern observed was qualitatively in line with our hypothesis.

Overall, the pattern emerging from the present investigation extends the conclusions of our earlier research in indicating that the control processes associated with encoding and retrieval processes are substantially different. These results suggest that differential effects of DA on encoding and retrieval may exist, because while encoding and secondary task performance are both under attentional control, retrieval operates largely outside of attentional control. Thus, during encoding, two controlled tasks must be managed concurrently, whereas during retrieval, only one task (the CRT task) requires control.

The novel contributions of the present research are, first, the finding that only certain types of concurrent task are associated with a decrement in memory encoding (i.e., tasks that involve central decision-making or central executive functions), and second, Experiment 2 shed light on a puzzle generated by our earlier work—that recall levels under DA conditions were lower than the levels predicted on the basis of a restriction in encoding time alone. The present results suggest strongly that DA at encoding also changes the qualitative type of encoding achieved, from a semantically elaborate kind of processing to a type of processing that is shallower and more phonemic in character.

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APPENDIX

The basic idea of the shared-time model proposed by Craik et al. (1996) is that time is a resource shared between the two tasks involved in a DA experiment. We make the simplifying assumption that processes occur in parallel only to the extent that there is sufficient time to execute the processes; thus, the processes associated with one task can be carried out only to the extent that time is "contributed" to them from the other task. In the present experiments, one task was memory encoding and the other was CRT. We therefore assume that, under DA conditions, the only time available for memory encoding is the time represented by the slowing of the CRT task (the time taken to perform the CRT task under DA conditions minus the time taken to perform the CRT task alone). For example, if mean RT under single-task conditions is 500 msec and this mean value rises to 800 msec under dual-task conditions, it is assumed that 300 msec are available for memory encoding processes. If the encoding phase lasts 60 sec, then 75 RT responses were made (60 sec/800 msec), and so 75 $\times$ 300 msec = 22.5 sec is supposedly available for memory encoding. If 10 items were encoded, then each item would have 2.25 sec available for encoding under DA conditions. In a different phase of the experiment, we present words at different rates (e.g., 2, 3, 4, 6 sec per word) for encoding under FA conditions. This procedure yields a "calibration function" relating encoding time to subsequent memory performance. Finally, in the present example, we take the observed level of memory performance under DA conditions and check whether it lies on the calibration function at the level of 2.25 sec.

When we carried out these calculations in the Craik et al. (1996) experiments, however, we found that the observed memory levels under DA fell substantially above the calibration function. We therefore made the further assumption that participants could also use the mechanical motor time in each CRT response for memory encoding; only the central decision time is unavailable. Motor time is estimated by having participants simply press the key repetitively without making decisions. If this motor time is 200 msec per keypress, then this value is added to the 300 msec available from each keypress (in the preceding example) to make a total of 500 msec available from each keypress under DA conditions—that is, 75 $\times$ 500 msec = 37.5 sec in total, or an amended value of 3.75 sec per item. When these amended calculations were carried out for the encoding conditions in the experiments reported by Craik et al. (1996), the observed memory values lay close to the calibration function, but below that function. Furthermore, the discrepancy between the observed values and those "predicted" by the calibration function increased as emphasis was shifted from the memory task to the CRT task, as described in the main body of the text of the present article.

(Manuscript received July 16, 1998;
revision accepted for publication September 3, 1999.)