Journal of Experimental Psychology:
Learning, Memory, and Cognition
2000, Vol. 26, No. 6, 1461–1482

0278-7393/00/$5.00 DOI: 10.1037//0278-7393.26.6.1461

Effects of Divided Attention on Encoding and Retrieval Processes: Assessment of Attentional Costs and a Componential Analysis

Moshe Naveh-Benjamin and Jonathan Guez
Ben-Gurion University of the Negev

Recent research has shown that divided attention at retrieval, in contrast to encoding, affected memory performance only minimally. This immunity at retrieval was associated with a significant secondary task cost. In this article the authors further investigated these effects employing a cued-recall task and a multimeasure approach with accuracy, latency, overall attentional costs, and the temporal distribution of attentional costs associated with the encoding and retrieval of low- and high-frequency words. The results of 2 experiments yielded a complex pattern of both similarities and differences between encoding and retrieval. Simultaneous inspection of the different measures of performance was instrumental in identifying 3 major types of retrieval (unsuccessful, slow, and fast), as well as different phases of the retrieval process, each of which was characterized by a different demand for attentional resources.

Earlier research on human memory suggested 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 hold that there is a necessary overlap between encoding and retrieval processes, in the sense that retrieval processes are involved in reinstating the same mental–neural operations that were active at encoding. Neuroscientists have also suggested that the same neural pathways mediate the perceptual processing of stimuli and their storage and recovery (Mishkin & Appenzeller, 1987; Moscovitch, 1992; Squire, 1992).

By contrast, recent studies using the divided attention (DA) paradigm have shown marked differences between encoding and retrieval processes. Dividing participants' attention between encoding the information presented and performing a secondary task has been shown to have a clear detrimental effect on memory performance relative to conditions in which full attention is paid to encoding the items (e.g., Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Murdock, 1965; Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000; Naveh-Benjamin, Craik, Guez, & Dori, 1998). DA at encoding has been shown to have a similar effect on a variety of memory features, including memory for frequency of occurrence (Naveh-Benjamin & Jonides, 1986), memory for spatial location (Naveh-Benjamin, 1987, 1988), and memory for temporal order information (Naveh-Benjamin, 1990).

Murdock (1965) found that free-recall performance was better when memory was emphasized at study than when card sorting, as a secondary task, was emphasized. Likewise, Craik et al. (1996) showed that encoding single words and word pairs results in a reliable decrement in secondary task performance. Furthermore, manipulating emphasis by instructing participants to stress the memory task, the secondary task, or both tasks equally has complementary effects on the two tasks: As attention is switched to the secondary task and away from the memory task, memory performance declines, and secondary task performance improves. These results indicate that encoding processes require attention and that the allocation of attention to encoding processes is under the participant's conscious control.

The effects of DA on retrieval processes are quite different. When attention was divided at retrieval, participants in the studies of Baddeley et al. (1984), Craik et al. (1996), Craik, Naveh-Benjamin, & Anderson (1998), Naveh-Benjamin et al. (1998), and Naveh-Benjamin, Craik, Perretta, and Tonev (2000), showed only small reductions in free recall, cued recall, and recognition performance. This relative immunity of memory to DA at retrieval was shown by Craik et al. (1996) and Naveh-Benjamin, Craik, Perretta, and Tonev (2000) to be accompanied by substantial secondary task reaction time (RT) costs that decreased from free recall to cued recall and recognition (see also Anderson, Craik, & Naveh-Benjamin, 1998; Griffith, 1976; Johnston, Greenberg, Fisher, & Martin, 1970; Johnston, Griffith, & Wagstaff, 1972).

Furthermore, instructing the participants to emphasize the memory task, the RT task, or both equally had no effect under DA at retrieval, even though secondary task RT performance was equally affected by these instructions during encoding and retrieval. Finally, Naveh-Benjamin et al. (1998) showed that encoding but not retrieval was sensitive to various task demands such as differences in word frequency. Craik et al. (1996) and Naveh-Benjamin et al. (1998) therefore suggested that retrieval processes are in some sense obligatory, or protected, but that their execution requires

Moshe Naveh-Benjamin and Jonathan Guez, Department of Behavioral Sciences, Ben-Gurion University of the Negev, Beer-Sheva, Israel.

This research was supported in part by a Ben-Gurion University Faculty of Humanities and Social Sciences extended grant. We are grateful to Yamit Azizi for her help in running and analyzing the data for Experiment 2 and to Michael Ginzburg for his programming assistance. We thank members of the memory research group and Neil Mulligan, Jeffrey Toth, and John Gardiner for helpful comments on an earlier version of this article.

Correspondence concerning this article should be addressed to Moshe Naveh-Benjamin, Department of Behavioral Sciences, Ben-Gurion University of the Negev, Beer-Sheva 84120, Israel. Electronic mail may be sent to naveh@bgumail.bgu.ac.il.

substantial resources, as shown by large secondary task costs. In contrast to earlier views, these studies provide strong evidence for dissimilarities between encoding and retrieval processes.

Evaluation of the large secondary task costs associated with what seems to be an obligatory retrieval process reveals interesting properties. A post hoc analysis of a free-recall task conducted by Craik et al. (1996, Experiment 1) indicated that certain processes at retrieval (e.g., those associated with actual retrieval) may not be resource demanding. No change in concurrent RT at retrieval as a function of number of items retrieved was shown during any particular segment of the retrieval phase in a free-recall task. These results suggest that a significant portion of the retrieval cost in free recall, as indicated by secondary task performance, is not related to processes associated with the retrieval itself but may be due to other processes. Craik et al. (1996) tentatively interpreted this cost as reflecting the placement of the cognitive system into a retrieval mode ("when the system is set for treating events as cues to stored episodes" [Tulving, 1983, p. 170]).

Although the results of Craik et al. (1996) imply that the extra secondary task cost in free recall is not related to the actual retrieval, the secondary task used by Craik et al. could have been methodologically problematic and hence may not warrant such a conclusion. The reason is that participants' responses to the secondary task, produced about every half second, along with the measurement of average RT every 5 s, could have allowed them to switch between tasks; even when participants retrieved two or three items per 5-s interval, they could have switched their attention between retrieval and the secondary task, resulting in an apparently fast RT. What is needed is a more sensitive and continuous measurement of secondary task performance that could allow the detection of even momentary changes in performance.

To analytically localize these costs during both the encoding and the retrieval period, Naveh-Benjamin et al. (1998, Experiment 2) used a free-recall task previously shown (e.g., Craik et al., 1996) to impose high demands for resources at retrieval and a newly devised tracking procedure as the secondary task to be performed along with encoding or retrieval. This procedure allows a microlevel analysis of momentary changes (every 5 ms) in participants' performance at virtually any moment during the encoding and retrieval phases by requiring them to track a fast-moving target on a computer screen with a mouse.

Naveh-Benjamin et al. (1998) split the encoding and the retrieval phases into two main subcomponents: those associated with the specific encoding or retrieval of "events" (the short interval before, during, and after each encoding or retrieval) and those associated with the remainder of the encoding or retrieval period (the intervals "between the events," i.e., encoding or retrieval of a word). The results of Experiment 2 of Naveh-Benjamin et al. (1998) replicated those obtained earlier showing that DA at encoding is affected by a secondary task. Retrieval, however, was not influenced by DA; free-recall performance was the same under full attention and DA conditions. This, nonetheless, was associated with substantial attentional costs as reflected in performance on the secondary tracking task. Naveh-Benjamin et al. showed that this extra cost at retrieval is distributed evenly throughout the retrieval phase and is not specific to the periods around the retrievals themselves. This last result strengthened the results of Craik et al. (1996), whose post hoc analysis showed no change in secondary task performance in free recall as a function of the number of items retrieved in a given interval. Interestingly, the pattern obtained for retrieval in the Naveh-Benjamin et al. (1998) study differs from encoding, in which there is a significant cost in secondary task performance around the time when the items are presented and presumably encoded.

A major purpose of the current study was to further assess the attentional costs associated with retrieval (and encoding). One issue concerns the uniform continuous cost in a free-recall task at retrieval reported by Naveh-Benjamin et al. (1998). Does this cost reflect the continuous operation of a retrieval mode in which there is no demand for resources by any given retrieval, as suggested by Naveh-Benjamin et al.? Or could it be that in a free-recall task, the periods between consecutive retrievals reflect a continuous search of the memory node network for candidates for retrieval? This search may require extended continuous attention and resources. Alternatively, this uniform continuous cost in free recall may reflect a failure to retrieve certain items, with these unsuccessful retrievals requiring as many resources as successful ones.

To answer this question, we used in the current studies a cued-recall task that, unlike a free-recall task, enables one to separate the attentional resources required into two retrieval subcomponents: the operation of a retrieval mode and the operation of search processes for a specific word. This can be achieved by evaluating the gradient of attention required, from the point at which a given cue is provided to the participant until she or he provides a retrieved response. Such demand for resources associated with search processes can be distinguished from consumption of resources by a retrieval mode throughout the retrieval period, which can be evaluated by the gradient of attention required from the point at which a retrieval response occurred until the point at which the next cue is presented. During this period, the participant is in a retrieval context but with no required specific retrieval activity.

A second issue addressed in the current research concerns the breakdown of retrievals into several distinct types. One type of retrieval that may require attentional resources is an unsuccessful one in which the search process does not result in a retrieved candidate. As noted earlier, a free-recall task may mask the attentional costs associated with unsuccessful retrievals, because there is no indication in such a task when an attempted retrieval of a given target has failed. The use of a cued-recall paradigm in the current study allowed us to specify and measure the attentional resources associated with unsuccessful retrievals.

There are several indications in the literature that the retrieval process is not unitary and that successful retrievals may be based on different mechanisms. For example, Jacoby (1991) distinguished between automatic retrievals based on familiarity mechanisms and controlled ones based on recollection. Gardiner and Java (1993) distinguished retrievals based on recollective experience (remember responses) from those based on familiarity only (know responses). The current study was intended to determine whether different types of successful retrievals can be distinguished and their associated attentional costs measured. This was accomplished by using another measure of performance: retrieval latency.

The use of a retrieval latency measure has several advantages. First, as mentioned earlier, it allows one to distinguish retrievals by their relative speed. Specifically, we sought to distinguish slow from fast retrievals and to examine the attentional resources associated with each. One plausible hypothesis is that these two types of retrieval require different amounts of attentional resources, as measured by the secondary tracking task, with fast ones requiring fewer resources. Such a hypothesis assumes that certain retrievals are effortful in that they require appreciable time and significant attentional resources for their execution, whereas other retrievals are automatic in that they are completed in a short duration and require few attentional resources (Hasher & Zacks, 1979).

Second, retrieval latency has been used in the past and has exhibited different performance patterns under DA manipulation than has the memory accuracy measure. For example, Baddeley et al. (1984) found that although a secondary task at retrieval had no effect on memory performance, it slowed the retrieval response. In addition, Carrier and Pashler (1995) used a methodology based on the psychological refractory period in which participants have to retrieve a previously presented item while performing a choice RT task within a very short interval. Their results indicated that memory retrieval was delayed by central processes in the choice task, supporting the assertion that memory retrieval and response selection are affected by a central bottleneck. Measuring retrieval latency as well as retrieval accuracy to assess the effects of DA at encoding and retrieval on both measures could provide a more comprehensive picture of performance. It could provide as well some indication regarding the replicability of Baddeley et al. (1984) and Carrier and Pashler's (1995) slowdown of retrieval responses under DA during retrieval. The use of retrieval latency will also allow the assessment of retrieval speed when attention is divided at encoding. One interesting question is whether division of attention during encoding, similarly to that reported for retrieval (e.g., Baddeley et al., 1984), will delay retrieval responses even though no bottleneck is involved, as is the case when attention is divided at retrieval.

In summary, a major purpose of the current study was to assess the secondary task costs associated with what seem to be obligatory retrieval processes, costs that are sometimes greater than those associated with encoding. Specifically, we wished to localize these costs during both encoding and retrieval periods as well as assess the costs associated with different phases of the retrieval period. We also wanted to differentiate the attentional costs associated with different types of retrievals (i.e., unsuccessful, slow–successful, and fast–successful). To this end, we used well-established memory paradigms in which encoding and retrieval phases are clearly separated. To avoid modality-specific interference, we presented the verbal information to be remembered auditorily and asked for spoken responses at retrieval, whereas the concurrent tasks involved visual stimuli and manual responses. We used a visual tracking task in which participants had to follow a fast-moving target on the computer monitor with a mouse.

We used a cued-recall task previously shown (e.g., Craik et al., 1996) to impose high demands for resources both at encoding and at retrieval, as well as a tracking procedure similar to the one used by Naveh-Benjamin et al. (1998) as the secondary task to be performed along with encoding or retrieval. This procedure allows a microlevel analysis of momentary changes in participants' performance by requiring participants to track a fast-moving target on a computer screen with a mouse. The program provides, in addition to an overall measure (as in previous studies), a temporal distribution measure of performance, which is the spatial distance between the target and the tracker every 20 ms in a continuous fashion. The exact times when stimuli are presented auditorily by the experimenter during encoding (cue–target) and retrieval (cue), and the exact times of participants' vocal responses during retrieval (target), are recorded by the computer through the use of a voice-operated relay and are superimposed on the continuous distance measure. This enables the measurement of tracking task performance at virtually any moment during the encoding and retrieval phases. Because performance on either task performed singly did not reach ceiling, we contend that each task required full attention when performed alone. When performed together, the tasks allowed assessment of performance throughout the dual-task interval. In particular, the secondary tracking task monitored and reflected the changes in attentional resources devoted to the encoding and retrieval of the words.

We created two aggregated segments of the temporal distribution of attentional resources, one for encoding and one for retrieval. At encoding, this was done by superimposing all 5-s segments in which a word pair was presented on top of each other and measuring the average attentional costs gradient in these 5 s. At retrieval, we superimposed all 5-s segments in which a cue was presented, and a retrieved response was or was not provided, on top of each other (see Results sections of the experiments for details). In both cases, the aggregated 5-s single tracking task used as a baseline was created, superimposed, and then subtracted from the aggregated encoding and retrieval segments in 20-ms slices. These segments provided us with a microlevel temporal distribution of the attentional resources required throughout the encoding and retrieval phases. We examined memory performance as well as secondary tracking task performance to confirm that, in such a paradigm, the previously obtained differential memory effects of DA at encoding and retrieval are found. Finally, retrieval latency was measured as the time between the presentation of the cue and the initiation of the response as recorded by the voice-operated relay. This latency allowed the differentiation of different types of retrievals (i.e., slow vs. fast). In addition, it allowed further evaluation of the symmetry between the effects of DA at encoding and retrieval not only on response accuracy, as in previous studies, but on response latency.

Experiment 1

Method

Participants

The participants were 57 undergraduates from the Ben-Gurion University of the Negev who took part in the experiment for course credit.

Design

The independent within-subject variable used was attention (i.e., full attention, DA at encoding, or DA at retrieval). The dependent variables were proportion of correctly recalled targets, performance on the secondary tracking task, and retrieval latency.

Table 1
Means for the Different Dependent Measures: Experiment 1

Measure	Full attention *M*	Full attention *SD*	DA–encoding *M*	DA–encoding *SD*	DA–retrieval *M*	DA–retrieval *SD*
Memory (percentage correct)	69.0	17.7	55.7	16.6	66.4	16.8
Latency (ms)	1,922	248.3	1,999	228.1	1,983	246.4
Secondary tracking task (distance in mm)	18.75[a]	6.9	1.88[b]	2.1	3.36[b]	3.3

Note. DA = divided attention.
[a]Performance on tracking task alone. [b]Tracking distance after tracking task baseline performance had been subtracted.

Stimuli

The words used were high-frequency two-syllable concrete nouns taken from Hebrew norms (Balgur, 1968). Nine lists were created, with 12 word pairs in each. The words in each pair were not related to each other semantically or in any other obvious way. The A–B pairs were presented auditorily at a pace of one every 5 s. At test, the A word of each pair was presented as a cue, and the participant had to produce the B response within 5 s (pilot work showed that there were very few responses provided after 5 s).

The tracking task involved a PC computer screen on which an asterisk moved at a rate of 6 cm/s in a smooth continuous fashion. This rate was chosen in a pilot study as one that is moderately difficult for participants when used alone (their performance indicated no ceiling effect, in that the distance measured was significantly higher than 0 mm). We designated four tracking paths that involved combinations of left–right and up–down directions. Although the movement of the asterisk appeared to be random, it had been predesignated for each path. Participants followed the asterisk with the mouse, which controlled a plus sign indicating their position on the screen, trying to stay as close as possible to the asterisk.

Procedure

Each participant was presented with the nine lists consisting of three replications of the three attention conditions. In addition, each participant performed the tracking baseline task four times, each time for 60 s (which was the length of both the encoding and retrieval phases). For each list, 12 word pairs were presented auditorily at a pace of one every 5 s for a total of 60 s of encoding. Participants then engaged in a 30-s distractor activity in which they had to subtract multiples of 7 from a number that appeared on the screen and write down their responses. Participants were told to perform the distractor task as quickly and as accurately as possible. After this interpolated activity, the cued-recall phase began, in which participants were given the A word of each pair as a cue and then had to produce the B response within 5 s. This was done for each pair, for a total of 60 s of retrieval. The order of the cues at retrieval was randomized.

Under the full attention condition, participants were told to pay full attention to the lists in encoding and retrieving them. In the tracking baseline condition, participants were instructed to catch the asterisk target or to follow it as closely as possible. In the DA conditions, they were told to pay equal attention to encoding or retrieval and to the tracking task. Before presentation of each list, participants were told which attention condition to expect.

There were four experimental conditions. In the single-task performance, memory full attention condition (three trials), participants were instructed to encode and retrieve information under full attention. In the single-task performance, tracking task condition (four trials), participants performed only the tracking task for 60 s. Each of the trials involved one of the four basic paths.[1] In the dual-task, DA at encoding condition (three trials), participants performed the encoding and the tracking task simultaneously, under instructions to pay equal attention to each. In these trials, retrieval was performed under full attention. We used three of the four predesignated paths, one for each trial. Finally, in the dual-task, DA at retrieval condition (three trials), participants encoded information under full attention and then performed the retrieval and the tracking task simultaneously, under instructions to pay equal attention to each. Again, three of the predesignated paths were used, one for each trial. Presentation of each word pair at encoding (via the tape recorder), presentation of the cue word at retrieval, and participants' vocal retrieval of each word triggered the voice-operated relay, which recorded the exact time at which each of these events was initiated.

Participants initially practiced the tracking task alone, the memory task alone (full attention), and their combination either at encoding (DA at encoding) or at retrieval (DA at retrieval). They then continued with the experimental trials. Nine task order formats were used in which the order of the nine memory trials (three for each attention condition) was counterbalanced with a Latin square design; 6 or 7 participants were assigned to each order. The four single tracking task trials were performed before the first list and after the third, sixth, and ninth lists. Participants' reports after the experiment indicated that they did not realize that the same four tracking task paths were repeated in the single- and dual-task conditions but perceived the movement of the asterisk to be random.

Results and Discussion

Memory Performance

Mean percentages of words recalled correctly across trials and participants for each condition appear in Table 1. Mean accuracy rates were 69.0% in the full attention condition, 55.7% in the DA at encoding condition, and 66.4% in the DA at retrieval condition. A one-way analysis of variance (ANOVA) showed a significant effect of attention, $F(2, 112) = 33.01$, $p < .01$, $MSE = 85.14$. A comparison of full attention and DA at

[1] About one third of the participants in Experiment 1 received the circular tracking task, which involved only one path (see Experiment 2). Overall, there were no differences in the pattern of tracking performance as a function of tracking task.

encoding showed a significant difference, $F(1, 56) = 54.08$, $p < .01$, $MSE = 92.72$, but a comparison of full attention and DA at retrieval did not, $F(1, 56) = 2.54$, *ns*, $MSE = 78.14$. The comparison of DA at encoding and DA at retrieval was significant, $F(1, 56) = 38.06$, $p < .01$, $MSE = 84.55$. These results replicated those reported in the literature and by Craik et al. (1996) and Naveh-Benjamin et al. (1998): DA at encoding resulted in a larger decrease in memory performance (13%) than DA at retrieval (2%). In terms of memory costs (percentage drop from the full attention condition), the decreases were 20% and 4% for encoding and retrieval, respectively.

Retrieval Latency

For each condition, we averaged the latency of all successful retrievals in each trial (latency for unsuccessful retrievals could not be determined, because participants provided no response). Mean latencies across trials and participants for each condition appear in Table 1. Means were 1,922 ms in the full attention condition, 1,999 ms in the DA at encoding condition, and 1,983 ms in the DA at retrieval condition. A one-way ANOVA showed a significant effect of attention, $F(2, 112) = 3.41$, $p < .05$, $MSE = 27{,}880$. A comparison of full attention with DA at encoding and DA at retrieval showed significant differences in both cases, $F(1, 56) = 5.67$, $p < .05$, $MSE = 30{,}080$, and $F(1, 56) = 4.02$, $p < .05$, $MSE = 26{,}583$, respectively, whereas a comparison of the two DA conditions showed no significant differences, $F(1, 56) = 0.27$, *ns*. These results replicated those reported by Baddeley et al. (1984) and Carrier and Pashler (1995) in showing that DA at retrieval slows retrieval responses. Interestingly, in this study, DA at encoding slowed retrieval responses significantly to the same degree as DA at retrieval. These results are elaborated on in the General Discussion section.

Tracking Task Performance

Retrieval versus encoding: Overall costs. For each attention condition (except the full one), we averaged the distance (in millimeters) between the target and the tracker after each 20-ms interval, over the whole trial. To provide a more precise measurement of encoding and retrieval DA costs, we subtracted the appropriate baseline distance for each trial by slicing both the DA condition and its paired single-task tracking control condition (which used the same spatial path) into 20-ms segments and subtracting the tracking distance performance on the single task from its corresponding list condition. This ensured a precise cost associated with the encoding or retrieval task every 20 ms when target paths were kept constant. The resultant overall tracking distances were 3.36 mm at retrieval and 1.88 mm at encoding (see Table 1), $t(56) = 3.71$, $p < .01$, thereby replicating the results of Experiments 1 and 2 of Craik et al. (1996) and the studies of Naveh-Benjamin et al. (1998), and indicating that retrieval requires more resources than encoding. These results also indicate that both encoding and retrieval required resources for their execution, as reflected by the distance measures being significantly larger than 0.0 mm, $ts(56) = 6.70$ and 7.60 for encoding and retrieval, respectively, $ps < .01$.

Because this study was intended not only to compare general resources associated with encoding and retrieval but also to specify the temporal distribution of these resources for encoding and retrieval, we created aggregated 5-s segments for encoding and retrieval (see Figure 1). For encoding, in which the presentation of a word pair by the experimenter occurred every 5 s, we superimposed for each participant the twelve, 5-s segments for each encoding trial and examined the distribution of tracking performance (after single-task tracking baseline had been subtracted). We then averaged performance on the three DA at encoding trials for each participant. For retrieval, the full 5-s segment was used in trials without a retrieval response (unsuccessful retrievals). For trials with a retrieval response (successful retrievals), participants gave their response at different points during the 5-s retrieval interval. For example, Figure 1 shows two retrieval segments; in one, the participant responded 1,800 ms after the cue was provided, and, in the other, she or he responded after 2,800 ms. To create the 5-s aggregated retrieval segment, one point in time has to be chosen to represent the prototypical retrieval time. We chose the 2-s mark, because this was the average retrieval latency of the participants (see the retrieval latency data described earlier). The next step involved taking all trials with a retrieval response and dividing them into two segments: cue presentation to response and response to next cue. We then took each of these two segments for each retrieval interval and superimposed them on the aggregated segment. If the segment cue to response was shorter than 2 s, the segment was stretched to fit a 2-s interval. For example, the first retrieval latency in Figure 1 was 1,800 ms, and in this case we stretched it to fit a 2-s interval. Likewise, if the retrieval response required more than 2 s, as is the case with the second retrieval response in Figure 1 (2,800 ms), the segment was compressed to fit the 2-s interval. The intervals from response to cue for each trial were superimposed on the aggregated 3-s interval after the response by either stretching or compressing them as necessary. This procedure produced a standardized relative positioning of tracking performance across all words with respect to the periods before and after the actual retrieval.

Each participant's tracking performance was averaged across the three DA at retrieval trials after baseline performance every 20 ms had been subtracted. Table 2 presents secondary task tracking performance (distance in millimeters) for the aggregated 5-s encoding and retrieval segments, averaged every half second across all participants. This tracking performance is analyzed subsequently.

Retrieval and encoding phases. To analyze the attentional costs associated with different phases of the retrieval process, we broke down the aggregated 5-s retrieval segment into three components. This segmentation was based on Tulving's (1983) taxonomy of subprocesses at retrieval, although it was also somewhat compatible with other taxonomies (e.g., those of Jacoby, 1998, and Guynn & McDaniel, 1999, both of whom suggested generate–recognize and direct retrieval routes; see the General Discussion section). The first component involved the encoding of the cue word, which lasted, on average, about 500 ms from the beginning of the mouthing of the cue by the experimenter, based on our measurements which indicated that it took the experimenter about 400–500 ms on the average to say the cue-word (we assumed that participants were encoding the cue, at least partially, while it was presented auditorily). The

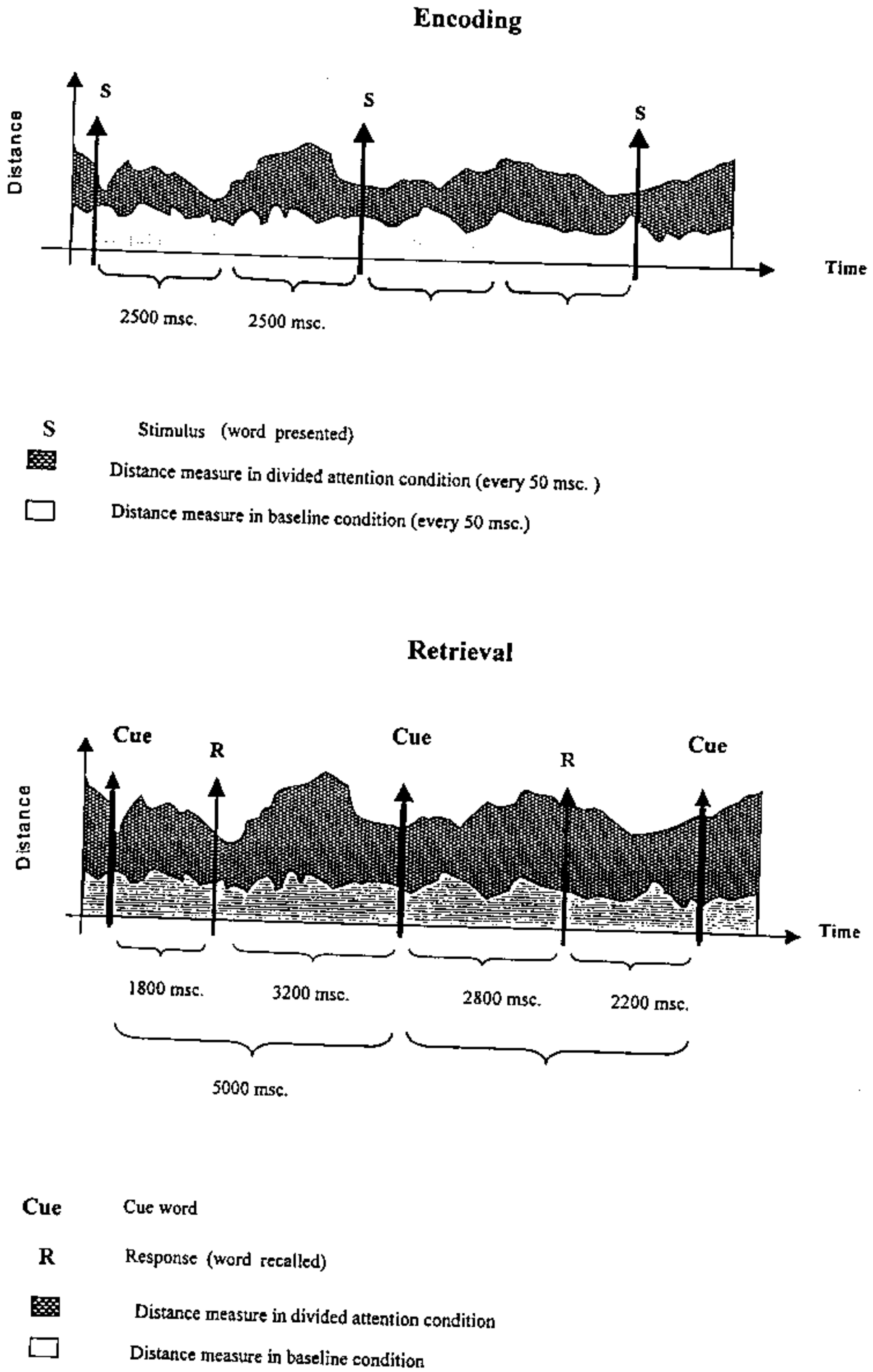

Figure 1. Time-line diagrams illustrating the creation of encoding and retrieval phases (see text).

second component involved cue elaboration or search for the appropriate target word, which began once the cue word was encoded and ended when the participant overtly retrieved the target word (or slightly earlier if, when the target was found, participants had to create a motor program to mouth the response). Because the average retrieval latency was 2,000 ms (as described earlier), the time between 0.5 and 2 s was designated as cue-elaboration–search time for retrievals. Finally, the time

Table 2
Secondary Tracking Task Means for the Different Encoding and Retrieval Segments as a Function of Time (Distance in Millimeters): Experiment 1

Encoding/retrieval types	Time																			
	0.0–0.5 s		0.5–1.0 s		1.0–1.5 s		1.5–2.0 s		2.0–2.5 s		2.5–3.0 s		3.0–3.5 s		3.5–4.0 s		4.0–4.5 s		4.5–5.0 s	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Encoding	1.8	3.2	1.7	3.0	1.7	3.0	2.1	3.1	2.2	2.7	2.2	2.9	2.1	3.0	2.0	3.1	1.9	2.9	2.0	2.7
Retrieval	2.7	3.2	3.6	3.7	3.9	4.8	3.9	4.6	3.5	4.8	3.5	4.7	2.9	4.1	3.0	3.4	3.4	3.7	3.1	3.8
Unsuccessful retrievals	2.6	3.8	3.7	4.4	4.2	5.2	4.6	6.2	4.7	6.1	4.7	6.3	4.3	5.1	4.1	4.8	4.4	5.2	4.1	5.5
Successful retrievals	2.3	3.6	3.2	3.9	3.6	5.0	3.2	4.1	2.4	4.9	2.2	4.6	2.0	4.4	2.0	3.6	2.4	3.6	2.1	3.7
Slow retrievals	2.2	4.8	3.4	4.7	3.8	6.2	3.6	5.2	2.5	5.9	2.5	5.5	2.5	5.4	2.4	4.5	2.6	4.4	2.7	3.8
Fast retrievals	2.6	4.1	1.5	4.2	1.5	4.7	1.5	4.7	1.7	4.4	1.0	4.4	0.6	4.2	0.9	3.4	1.3	3.9	0.2	4.6

between a successful retrieval and the appearance of the next cue was designated as a retrieval mode, because participants were presumably not engaged in any active retrieval during this period.[2]

As a means of allowing for comparison across participants, this segmentation was performed on the adjusted retrieval segments, as described earlier. Note that performance in the baseline single-task tracking condition did not exhibit any particular pattern during the different phases. Furthermore, it did not vary systematically across the different phases.

To isolate the costs associated with each of the retrieval components and to simplify the analysis, we used the first data point in Table 2 (0.0 to 0.5 s) to estimate the attentional cost associated with cue encoding; the mean of the second, third, and fourth data points (0.5–1.0 to 1.5–2.0 s) to estimate the cost associated with cue elaboration–search; and the mean of the sixth, seventh, eighth, and ninth data points (2.5–3.0 to 4.0–4.5 s) to estimate the cost associated with retrieval mode. We did not include in this analysis either the fifth data point (2.0–2.5), because in some of the trials it was associated with retrievals, or the tenth data point (4.5–5.0), because it could reflect anticipation of the next cue word. For comparison purposes only, we similarly designated the respective periods during encoding as stimulus encoding, encoding processes, and encoding mode. Such segmentation of encoding was fairly arbitrary and based on segmentation at retrieval. For example, the encoding processes phase could occupy the entire period after the stimuli had been encoded rather than being followed by an encoding mode phase (see General Discussion). The resultant means appear in Table 3.

Several patterns can be observed in Table 3. First, as already mentioned, both encoding and retrieval required attentional resources for their execution, reflected by the distance function being above the baseline (0.0 mm). Second, there seemed to be no effect of phase. Finally, there seemed to be an interaction between the two variables in which the difference between encoding and retrieval was greatest in the cue-elaboration–search phase. A two-way ANOVA indicated that the effect of encoding–retrieval was significant, $F(1, 56) = 11.30, p < .01, MSE = 15.94$; the effect of phase–component was not significant, $F(2, 112) = 2.27$, *ns*, $MSE = 3.99$; and the interaction of the two was significant, $F(2, 112) = 3.17, p < .05, MSE = 3.03$. Several follow-up analyses were performed on the significant interaction. Analysis of simple effects of encoding phase–component indicated no significant differences, $F(2, 112) = 0.12$, *ns*, $MSE = 3.78$. A similar analysis for retrieval indicated significant differences, $F(2, 112) = 3.79$, $p < .05, MSE = 4.25$. Follow-up simple comparisons for retrieval indicated that the distance measure was larger in the cue-elaboration–search phase than in the cue-encoding phase, $F(1, 56) = 8.81, p < .01, MSE = 3.64$.

These results indicate, as discussed in the introduction, that in contrast to the results reported in Experiment 2 of Naveh-Benjamin et al. (1998) for a free-recall task, there is an attentional cost associated with specific retrievals, a cost that may have been concealed in that experiment by the use of a free-recall task. When a cued-recall task, which enables the separation of specific phases at retrieval, is used, there seem to be extra attentional costs associated with cue-elaboration–search processes for a particular target (see General Discussion).

Successful versus unsuccessful retrievals. In the preceding analysis, all retrievals were treated alike. However, with the criterion of no overt retrieval response, retrieval was unsuccessful in more than one third of the trials. As mentioned in the introduction, such retrievals may involve different resource demands. One possibility is that in contrast to successful retrievals, in which the cue-elaboration–search process terminates after a candidate has been retrieved, cue-elaboration–search processes in unsuccessful retrievals may continue for the whole 5-s period until the next cue appears. To specify the attentional costs associated with unsuccessful retrievals, we separated those trials in which participants provided no retrieved response (designated unsuccessful retriev-

[2] An alternative way of analyzing the data is to take tracking performance during the retrieval mode phase as a baseline (representing background activity throughout the retrieval period) and evaluate the extra costs associated with either cue encoding or cue elaboration–search by subtracting the tracking distance during the retrieval mode period from that associated with either cue encoding or cue elaboration–search. We decided to use the raw data instead, because the use of difference scores may create dependency between the measures, potentially violating ANOVA assumptions.

Table 3
Secondary Tracking Task Means for the Different Phases of the Encoding and Retrieval Segments (Distance in Millimeters): Experiment 1

Encoding/retrieval types	Phase: Cue encoding[a] *M*	*SD*	Cue elaboration–search[b] *M*	*SD*	Mode *M*	*SD*
Encoding	1.74	3.2	1.80	2.8	2.07	2.7
Retrieval	2.69	3.2	3.76	3.9	3.25	3.7
Successful retrievals	2.32	3.6	3.10	3.9	2.17	3.7
Unsuccessful retrievals	2.64	3.8	4.14	4.7	4.39	4.8
Slow retrievals	2.26	4.8	3.60	4.9	2.54	4.6
Fast retrievals	2.65	4.1	1.54	3.6	0.95	2.8

[a] For encoding: pair encoding (see text). [b] For encoding: encoding period (see text).

als) from those in which a retrieved response was provided (designated successful retrievals; in 97% of the cases in which a word was retrieved, it was the correct one, and thus we took all trials in which a response was given to indicate successful retrievals). Table 2 presents secondary task tracking performance (distance in millimeters) for the aggregated 5-s successful and unsuccessful retrieval segments after single-task tracking performance had been subtracted, averaged across all participants.

As Table 2 indicates, the cost associated with the retrieval period, as reflected by the distance measure, varied as a function of whether or not a retrieval was successful. Secondary task costs associated with unsuccessful retrievals (4.13 mm) were larger than those associated with successful ones (2.49 mm), $t(56) = 2.78$, $p < .01$. Both types of retrieval required attentional resources for their execution, as reflected by the distance measure being significantly larger than 0.0 mm, $ts(56) = 7.19$ and 5.85 for unsuccessful and successful retrievals, respectively, $ps < .01$.

To analyze the attentional costs associated with different phases of the retrieval period for successful and unsuccessful retrievals, we broke down the 5-s retrieval period into the three components mentioned earlier (cue encoding, cue elaboration–search, and retrieval mode). Note that, for unsuccessful retrievals, the cue-elaboration–search period could be extended for the full 5 s as participants tried to search for the relevant target throughout the retrieval period until the next cue was presented. Nevertheless, to enable the comparison of these results with those presented earlier, we kept the same time parameters for each of the phases–components. The resultant means appear in Table 3.

Inspection of Table 3 indicates that unsuccessful retrievals resulted in a larger tracking distance measure than successful ones. In addition, the cue-elaboration phase seemed to be associated with larger tracking distances than the cue-encoding phase. Finally, there was an apparent interaction between the two variables. A two-way ANOVA with retrieval type as one variable and phase–component as the other confirmed these observations. The effect of retrieval type was significant, $F(1, 56) = 4.56$, $p < .05$, $MSE = 26.74$, as were the effects of phase–component, $F(2, 112) = 5.96$, $p < .01$, $MSE = 6.53$, and the interaction of the two variables, $F(2, 112) = 4.31$, $p < .05$, $MSE = 6.08$.

Several follow-up analyses were performed. Analysis of interaction comparisons for the cue-encoding and cue-elaboration–search phases indicated a significant increase in the distance tracking measure from the first to the second phase, $F(1, 56) = 13.19$, $p < .01$, $MSE = 5.60$, but no significant interaction with retrieval type, $F(1, 56) = 1.15$, *ns*, $MSE = 6.34$. This suggests a significant increase in attentional resources when moving from the cue-encoding to the cue-elaboration–search phase for both types of retrieval. Analysis of interaction comparisons for cue-elaboration–search and retrieval mode phases indicated an interaction with retrieval type that approached statistical significance, $F(1, 56) = 3.68$, $p < .06$, $MSE = 6.08$. Further contrast comparisons showed that whereas there was a significant decrease in the distance measure from the second to the third phase for successful retrievals, $F(1, 56) = 4.08$, $p < .05$, $MSE = 6.91$, there were no significant differences between these two phases for unsuccessful retrievals, $F(1, 56) = 0.33$, *ns*, $MSE = 5.33$.

In general, these analyses revealed a substantial increase in attentional resources associated with cue-elaboration–search processes, accompanied by a decrease in these resources once a retrieval was successful. For unsuccessful retrievals, participants' continuous search for the target was associated with substantial attentional resources being required after cue encoding and throughout the retrieval period. This could have been related to particular pairs that were difficult to link together (see General Discussion).

Fast versus slow retrievals. To assess potential differences among the successful retrievals, we split them into two groups: fast retrievals, comprising retrievals with response latencies of 1,400 ms or less ($M = 1,193$ ms), and slow retrievals, comprising retrievals with response latencies above 1,400 ms ($M = 2,192$ ms). The designation of latency below 1,400 ms as the criterion for fast retrievals was established to create a group of retrieval responses that were made within less than 1 s after the cue word has been completed (based on an estimation of 500 ms as the time required for the experimenter to mouth the cue word). This resulted in 25% of all successful retrievals being fast and 75% being slow.[3]

To assess attentional costs required by the slow and fast retrievals, we split the distance measure reported earlier for successful retrievals, separately examining fast and slow ones. Because participants' retrieved responses were given at different points during the 5-s retrieval interval for these two types of retrieval, we used the same methods described earlier to create two aggregated retrieval segments, one with the retrieval response at approximately 1,200 ms (for fast retrievals) and the other with the retrieval response at approximately 2,200 ms (for slow retrievals). For fast retrievals with an actual retrieval latency longer or shorter than 1,193 ms (their mean latency), the tracking performance distribution was adjusted to fit a 1,200-ms interval before the retrieval response and a 3,800-ms interval after the response (altogether, a 5-s retrieval interval). For slow retrievals with an actual retrieval latency longer or shorter than 2,192 ms (their mean latency), the tracking performance distribution was adjusted to fit a 2,200-ms interval before the retrieval response and a 2,800-ms

[3] Analyses based on splits of slow and fast retrievals at latencies from 1,200 to 1,600 ms resulted in similar patterns of tracking task performance, as described later in the text.

interval after the response. This produced a standardized relative positioning of tracking performance across all words with respect to the periods before and after the actual retrieval.

Each participant's tracking performance was, as before, averaged across the three DA at retrieval trials after baseline performance every 20 ms had been subtracted. Figure 2 and Table 2 present the secondary task tracking performance (distance in millimeters) of the aggregated 5-s fast and slow successful retrieval segments averaged across all participants (the unsuccessful retrievals and the encoding segments were added to Figure 2 for purposes of comparison with the successful retrievals). This secondary task performance represents the overall temporal distribution of attentional costs associated with encoding and with each type of retrieval.

Inspection of Figure 2 reveals different patterns for fast and slow retrievals. Mean secondary task distance was larger for slow retrievals (2.83 mm) than for fast ones (1.30 mm), $t(56) = 2.57$, $p < .05$. Both types of retrieval required attentional resources for their execution, as reflected by the distance measure being significantly larger than 0.0, $ts(56) = 5.11$ and 3.74 for slow and fast retrievals, respectively, $ps < .01$.

To assess changes in attentional resources for slow and fast retrievals over the retrieval period, and to analyze the attentional costs associated with different phases of the retrieval process, we again broke down the 5-s retrieval interval into three components (cue encoding, cue-elaboration–search, and retrieval mode). The resultant means appear in Table 3.

Inspection of Table 3 reveals that slow retrievals resulted in a larger tracking distance measure than fast ones. In addition, the retrieval mode phase seemed to result in smaller tracking distances than the cue-elaboration–search phase. Finally, there was evidence of an interaction between the two variables. A two-way ANOVA with retrieval type as one variable and phase–component as the other indicated that the effect of retrieval type approached statistical significance, $F(1, 56) = 2.78$, $p < .10$, $MSE = 36.35$, and that the effect of phase–component was significant, $F(2, 112) = 3.02$, $p < .05$, $MSE = 7.04$. Most important, the interaction was significant, $F(2, 112) = 7.64$, $p < .01$, $MSE = 6.01$.

Several follow-up analyses were performed on the significant interaction. An analysis of interaction comparisons involving cue-encoding and cue-elaboration–search phases and fast and slow retrievals showed a significant interaction, $F(1, 56) = 13.07$, $p < .01$, $MSE = 6.06$. Further contrast comparisons showed that whereas there was no difference between slow and fast retrievals in the cue-encoding phase, $F(1, 56) = 0.22$, *ns*, $MSE = 21.00$, there was a significant difference between the two retrieval types in the cue-elaboration–search phase, $F(1, 56) = 7.57$, $p < .01$, $MSE = 14.38$, in which slow retrievals were associated with larger tracking distances (more attentional resources). The different patterns of the distance measure in the cue-encoding and cue-elaboration–search components for slow and fast retrievals were also apparent when contrasts were used to compare phases within each type of retrieval. For slow retrievals, the contrast comparing the cue-encoding and cue-elaboration–search phases was significant, $F(1, 56) = 8.13$, $p < .01$, $MSE = 5.34$, indicating an increase in the distance measure. For fast retrievals, the same contrast, which had been significant, $F(1, 56) = 5.06$, $p < .05$, $MSE = 7.10$, indicated the opposite trend, that is, a decrease in the distance measure.

Analysis of interaction comparisons involving the cue-elaboration–search and retrieval mode phases for slow and fast retrievals indicated a significant decrease in the distance measure when moving from the cue-elaboration–search phase to the retrieval mode phase, $F(1, 56) = 8.41$, $p < .01$, $MSE = 21.30$. There was no significant interaction, however, $F(1, 56) = 0.30$, *ns*, $MSE = 6.07$.

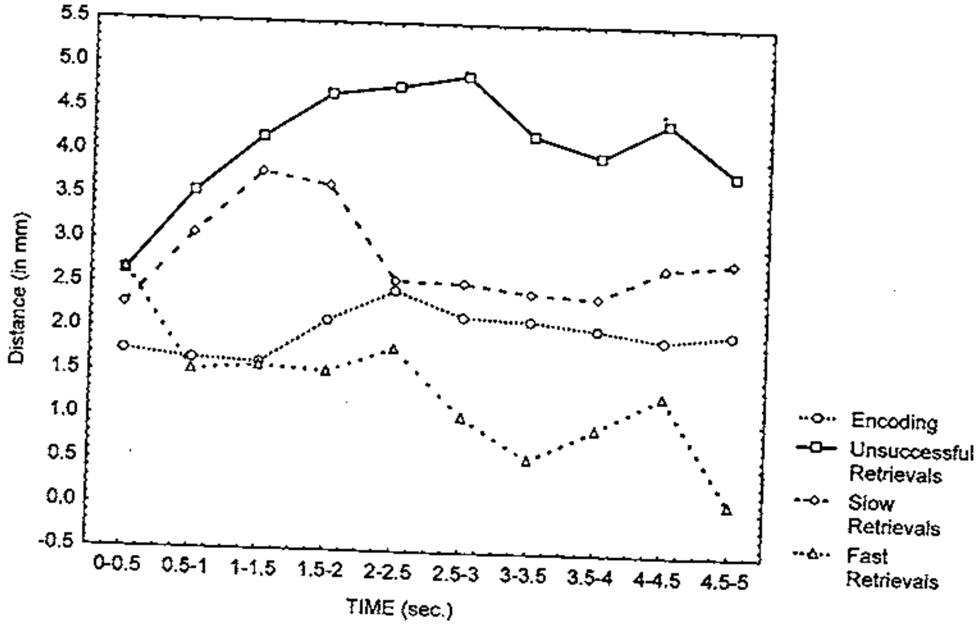

Figure 2. Temporal distribution of performance on the secondary tracking task for the aggregated 5-s encoding, unsuccessful retrieval, slow retrieval, and fast retrieval segments after single-task tracking performance subtraction (distance in millimeters): Experiment 1.

Altogether, these analyses reveal that slow retrievals are associated with substantial increases in attentional resources during cue-elaboration–search processes, accompanied by a decrease in these resources once a retrieval is successful. By contrast, fast retrievals, if anything, are associated with a decrease in attentional resources during the cue-elaboration–search phase.

Overall, the results of this study provide converging evidence related to results reported in the past and, at the same time, supply novel information regarding the attentional costs associated with encoding and retrieval processes. The results replicated previous findings (e.g., Craik et al., 1996; Naveh-Benjamin et al., 1998) in showing an asymmetry between encoding and retrieval processes in the effects of DA on both memory and secondary task performance. They seem to show that retrieval processes are protected but that this protection requires substantial attentional resources. Combining information from secondary task performance and latency of retrieval measures showed that this demand for resources is differentially associated with type of retrieval; unsuccessful retrievals requiring more resources than successful ones, and slow retrievals requiring more resources than fast ones. In addition, the results indicate that retrieval latency is slowed by about the same degree under DA at either encoding or retrieval.

Data regarding the temporal distribution of the attentional resources associated with encoding and retrieval provided important information regarding these processes, information not obtained when, as in previous research, overall resources are evaluated. This can be nicely demonstrated by comparing the results of Figure 2 and Figure 3. Figure 3, which provides information only about overall resources dedicated to the tasks, indicates, for example, that slow but successful retrievals require fewer resources than unsuccessful ones and more resources than fast ones. Such information masks the fact that slow retrievals are also similar to the other types of retrievals in their attentional resource consumption. In particular, slow retrievals are similar to unsuccessful ones in terms of resources required during the cue-encoding and cue-elaboration–search phases but differ from unsuccessful retrievals once the retrieval is complete. Likewise, slow retrievals are similar to fast retrievals during the cue-encoding phase but different later. This information, which appears in Figure 2, can be revealed only by a detailed microlevel temporal analysis of secondary task performance, as done here. The results of such a temporal analysis of resources showed that demand for resources is differentially associated with component–phase of retrieval; cue-elaboration–search processes requiring more resources than other processes.

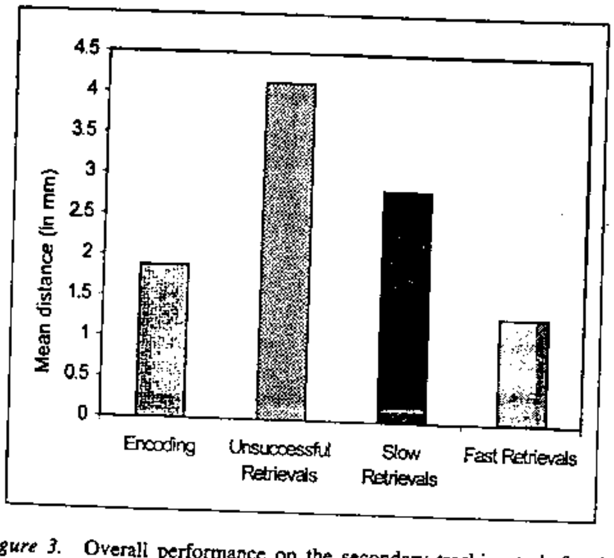

Figure 3. Overall performance on the secondary tracking task for the encoding, unsuccessful retrieval, slow retrieval, and fast retrieval segments after single-task tracking performance subtraction (distance in millimeters): Experiment 1.

Experiment 2

The purpose of Experiment 2 was twofold. First, we wanted to test the replicability of the results of Experiment 1 and establish the usefulness of our multimeasure approach. Second, we wished to evaluate several hypotheses related to the results obtained in Experiment 1. In particular, we manipulated the types of materials encoded and retrieved by comparing the materials used in Experiment 1—frequent words in the language—with infrequent words, which are more difficult to recall (Gregg, 1976). In Experiment 1 of Naveh-Benjamin et al. (1998), we used this manipulation and showed that infrequent words had the same effect as frequent words under DA conditions: At encoding DA caused a significant drop in memory performance, whereas at retrieval DA did not interrupt memory retrieval even for such infrequent words. This resilience of retrieval processes, however, was associated with increased secondary task costs that were greater for infrequent words than for frequent ones. Overall, the picture emerging from the 1998 study is that of retrieval processes that are immune to the effects of DA, with this immunity, however, being associated with a cost that is proportional to the difficulty of the retrieval task.

In the current experiment, we compared high-frequency and low-frequency words under conditions of full attention and DA either at encoding or at retrieval. We used the same multimeasure approach as in Experiment 1 to provide information on the following questions. First, does the same pattern of memory performance for low- and high-frequency words emerge as in Experiment 1 of Naveh-Benjamin et al. (1998)? Second, what is the pattern of retrieval latency for low- and high-frequency words? Specifically, will low-frequency words behave under DA conditions, either at encoding or at retrieval, as high-frequency words did in Experiment 1, showing the same pattern of slowdown relative to a full attention condition? Experiment 1 of Naveh-Benjamin et al. (1998), which involved high- and low-frequency words, did not examine this latency measure.

Third, and of considerable importance, is the question of the source of the extra attentional costs associated with the retrieval of low-frequency words as reported by Naveh-Benjamin et al. (1998). Is this the result of a more demanding cue-encoding process? That is, are more attentional resources required to encode low-frequency words as a result of slower access to the semantic memory representations of these words? Alternatively, the increase in attentional costs associated with the retrieval of low-frequency words may be related to more demanding cue-elaboration–search processes. For example, low-frequency words as cues may not provide as much information as their high-frequency counterparts, and hence further cue elaboration is necessary to retrieve the context at encoding. Another possibility is that the greater attentional cost of retrieving low-frequency words is related to a higher retrieval mode for these words. For example, downloading retrieval procedures and holding them in working memory may require more attentional capacity for low-frequency words than for high-frequency ones. Finally, these extra attentional costs may be related to the different combinations of retrieval types for low- and high-frequency words. For example, the greater retrieval cost for infrequent words could be due to the higher proportion of unsuccessful retrievals for these words than for frequent ones. As indicated by the results of Experiment 1, these unsuccessful retrievals are associated with larger attentional costs. Finally, the extra attentional costs associated with the retrieval of low-frequency words could be due to the larger proportion of slow (relative to fast) retrievals for these words in comparison with their high-frequency counterparts. As shown in Experiment 1, slow retrievals require extra costs for their execution. To determine slow and fast retrievals, we measured retrieval latency in this experiment as in Experiment 1.

To answer the questions posed, we used the multimeasure approach used in Experiment 1, including measures of memory accuracy, retrieval latency, attentional costs, and the temporal distribution of attentional costs during encoding and retrieval. We used a secondary task methodology similar to that used in Experiment 1, allowing a microlevel temporal analysis of the secondary task costs associated with encoding and retrieval of low-frequency and high-frequency words. The tracking task itself was a similar but slightly different task in which an asterisk moved in a circular path 12 cm in diameter. Participants followed the asterisk with the mouse, which controlled a plus sign indicating position on the screen, trying to keep as close as possible to the target while remaining within the path. We used this task in a pilot study, and it was shown to produce similar patterns in participants' tracking performance to the task used in Experiment 1.

Method

Participants

The participants were 65 undergraduates from the Ben-Gurion University of the Negev who took part in the experiment for course credit.

Design

Two independent within-subject variables were used. One was attention: full attention, DA at encoding, or DA at retrieval. The other was frequency in the language of the words presented: either low frequency or high frequency. The dependent variables were proportion of correctly recalled targets, performance on the secondary tracking task, and retrieval latency.

Stimuli

The words used were two-syllable or three-syllable concrete nouns. Twelve lists were created, with 12 word pairs in each. Six of the lists contained high-frequency words (more than 200 per million), and the other six contained low-frequency words (less than 30 per million). The words were taken from Hebrew norms (Balgur, 1968). The words in each pair were not related to each other semantically or in any other obvious way. The A–B pairs were presented auditorily at a pace of one every 5 s. At test, the A word of each pair was presented as a cue, and the participant had to produce the B response within 5 s.

The tracking task involved a PC computer screen on which an asterisk moved within a 1-cm-wide circular path of 12 cm in diameter at a rate of 6 cm/s. This rate was chosen in a pilot study as one that is moderately difficult for participants when used alone (their performance indicated no ceiling effect, in that the distance measured was significantly higher than 0 mm). Participants followed the asterisk with the mouse, which controlled a plus sign indicating their position on the screen, trying to keep as close as possible to the target while remaining within the path.

Procedure

Each participant was presented with the 12 lists consisting of two replications of all combinations of the three attention conditions and the two frequency levels. In addition, each participant performed the tracking baseline task twice, each time for 60 s (which was the length of both the encoding and retrieval phases). The lists were presented at a pace of one pair every 5 s, exactly as in Experiment 1. After the interpolated activity of 30 s, the retrieval phase in which cues were presented every 5 s proceeded exactly as in Experiment 1. Participants in each of the three attention conditions received the same instructions as in Experiment 1. The same four experimental trials used in Experiment 1 were used (four memory, full attention trials; two single tracking task trials; four DA at encoding trials; and four DA at retrieval trials).

The use of the voice-operated relay was as in Experiment 1. Participants initially practiced the tracking task alone, the memory task alone (full attention), and their combination either at encoding (DA at encoding) or at retrieval (DA at retrieval). They then continued with the experimental trials. Twelve task order formats were used in which the order of the 12 memory trials (4 for each attention condition) was counterbalanced with a Latin square design; 5 or 6 participants were assigned to each order. The two single tracking task trials were performed before the fourth and the eighth lists.

Results and Discussion

Memory Performance

Mean percentages of words recalled correctly across trials and participants for each condition appear in Table 4. A two-way ANOVA with attention condition and word frequency as variables indicated a significant effect of word frequency, $F(1, 64) = 138.70$, $p < .01$, $MSE = 214.74$, showing that high-frequency words ($M = 68.5\%$) were better remembered than low-frequency words ($M = 51.0\%$). The ANOVA also indicated a significant effect of attention, $F(2, 128) = 17.22$, $p < .01$, $MSE = 107.05$. A comparison of full attention ($M = 61.8\%$) and DA at encoding ($M = 55.4\%$) showed a significant difference, $F(1, 64) = 19.59$, $p < .01$, $MSE = 139.04$, but a comparison of full attention and DA at retrieval ($M = 61.9\%$) did not, $F(1, 64) = 0.01$, *ns*. The comparison of DA at encoding and DA at retrieval was significant, $F(1, 64) = 26.93$, $p < .01$, $MSE = 104.19$. The interaction of the two variables was not significant, $F < 1.0$. These results replicated those reported by Craik et al. (1996), by Naveh-Benjamin et al. (1998), and in the present Experiment 1; DA at encoding resulted in a sharper drop in memory performance (6.4%, which is somewhat smaller than the usual result obtained; see later discussion) than DA at retrieval (0%). In terms of memory costs (percentage drop from the full attention condition), decreases were 10.4% and 0% for encoding and retrieval, respectively. In this experiment, as in Experiment 1, there was no memory cost associated with divided attention at retrieval. These results also replicated the results obtained by Naveh-Benjamin et al. (1998) for word frequency, showing better cued recall for high- than for low-frequency words.

Table 4
Means for the Different Dependent Measures for High-Frequency and Low-Frequency Words: Experiment 2

Measure	Attention condition					
	Full attention		DA–encoding		DA–retrieval	
	M	*SD*	*M*	*SD*	*M*	*SD*
Memory (percentage correct)						
High frequency	71.2	14.6	64.0	16.3	70.3	14.3
Low frequency	52.6	19.5	46.8	18.7	53.6	19.2
Latency (ms)						
High frequency	1,958	350.8	2,077	381.3	2,035	334.7
Low frequency	2,059	322.0	2,285	407.2	2,214	415.4
Secondary tracking task (distance in mm)						
High frequency	19.7[a]	14.7	1.43[b]	5.8	1.68[b]	6.1
Low frequency	19.7[a]	14.7	2.68[b]	6.7	3.75[b]	11.1

Note. DA = divided attention.
[a] Performance on tracking task alone. [b] Tracking distance after tracking task baseline performance had been subtracted.

Retrieval Latency

For each condition, we averaged the latency of all successful retrievals in each trial (latency for unsuccessful retrievals could not be determined, because participants provided no response). Mean latencies across trials and participants for each condition appear in Table 4. Means were 2,009 ms in the full attention condition, 2,181 ms in the DA at encoding condition, and 2,125 ms in the DA at retrieval condition. A two-way ANOVA showed a significant effect of attention, $F(2, 128) = 10.35, p < .01, MSE = 96{,}547$. A comparison of full attention with DA at encoding and DA at retrieval showed significant differences in both cases, $F(1, 64) = 18.98, p < .01, MSE = 101{,}313$, and $F(1, 64) = 10.75, p < .05, MSE = 80{,}960$, respectively. The comparison of the two DA conditions showed no significant differences, $F(1, 64) = 1.92$, *ns*. These results replicated those obtained in Experiment 1 in showing that DA both at encoding and at retrieval slowed retrieval responses significantly, and to the same degree, relative to the full attention condition. The effect of word frequency was also significant, $F(1, 64) = 23.72, p < .01, MSE = 108{,}708$, showing slower responses for low-frequency (M = 2,186 ms) than for high-frequency (M = 2,023 ms) words. Finally, the interaction of the two variables was not significant, $F < 1.0$.

Tracking Task Performance

Retrieval versus encoding: Overall costs. As in Experiment 1, for each attention condition (except the full one), we averaged the distance (in millimeters) between the target and the tracker after each 20-ms interval over the whole trial. To provide a more precise measurement of encoding and retrieval DA costs, we subtracted the appropriate baseline distance (averaged over the two baseline trials) for each trial. The resultant overall tracking distance was in the same direction as in Experiment 1, with values of 2.69 mm at retrieval and 2.05 mm at encoding (see Table 4). A two-way ANOVA with attention condition (DA at encoding and at retrieval) and word frequency as the two variables indicated that the effect of attention was not significant, $F < 1.0$. This result reflects the fact that, in a cued-recall task, retrieval does not always require more resources than encoding (e.g., Craik et al., 1996, Experiment 3; Naveh-Benjamin et al., 1998, Experiment 1). The results also indicate that both encoding and retrieval required resources for their execution, as reflected by the distance measures being significantly larger than 0.0 mm, $ts(64) = 3.19$ and 2.76 for encoding and retrieval, respectively, $ps < .01$. There was a significant effect of word frequency; low-frequency words required more resources (M = 3.20) than high-frequency words (M = 1.55), $F(1, 64) = 5.36, p < .05, MSE = 32.58$, replicating the results of Naveh-Benjamin et al. (1998, Experiment 1). The interaction of the two variables was not significant, $F < 1.0$.

Because this experiment, as was Experiment 1, was intended to specify the temporal distribution of these resources for encoding and retrieval, we created, as in Experiment 1, aggregated 5-s segments for encoding and retrieval for each word frequency separately (for a detailed description, see Figure 1 and related text in Experiment 1). Each participant's tracking performance was averaged across the two DA at encoding and DA at retrieval trials, for each word frequency level, after baseline performance every 20 ms had been subtracted. Table 5 presents secondary task tracking performance (distance in millimeters) for the aggregated 5-s encoding and retrieval segments for each word frequency level, averaged every half second across all participants.

Retrieval and encoding phases. To analyze the attentional costs associated with different phases of the retrieval process, we broke down the aggregated 5-s retrieval segment into three components—cue encoding, cue elaboration–search, and retrieval mode—as in Experiment 1. Similar segmentation was used for encoding. To isolate the costs associated with each of the encoding–retrieval phases–components, we combined data points from Table 5 together, as in Experiment 1. The resultant means appear in Table 6.

Several patterns can be observed in Table 6. First, as already mentioned, both encoding and retrieval required attentional resources for their execution, as reflected by the distance function being above the baseline (0.0 mm). Second, there seemed to be an

Table 5

Secondary Tracking Task Means for the Different Encoding and Retrieval Segments of High-Frequency and Low-Frequency Words as a Function of Time (Distance in Millimeters): Experiment 2

Encoding/retrieval types	Time																			
	0.0–0.5 s		0.5–1.0 s		1.0–1.5 s		1.5–2.0 s		2.0–2.5 s		2.5–3.0 s		3.0–3.5 s		3.5–4.0 s		4.0–4.5 s		4.5–5.0 s	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Encoding																				
High frequency	1.4	5.3	1.3	5.7	1.7	6.3	1.8	6.7	1.8	6.7	1.5	6.3	1.3	6.1	1.3	6.1	1.1	6.2	1.1	6.0
Low frequency	2.0	7.0	1.8	7.3	2.5	7.2	2.7	6.8	3.1	7.1	3.0	7.2	3.2	7.3	3.1	7.1	3.0	7.2	2.5	6.9
Retrieval																				
High frequency	1.5	6.2	2.0	6.7	2.5	7.3	2.6	7.6	2.2	7.7	1.5	6.5	1.2	5.5	1.0	5.6	1.2	5.5	1.3	5.9
Low frequency	3.3	10.1	4.3	11.1	4.4	10.8	4.6	11.3	4.2	11.4	3.7	11.8	3.2	12.3	3.1	12.1	3.1	11.1	3.1	9.8
Unsuccessful retrievals																				
High frequency	1.9	9.1	2.7	10.2	3.0	10.3	3.8	11.3	3.9	11.6	3.3	10.8	2.8	10.6	2.7	10.5	2.6	10.2	2.8	10.1
Low frequency	2.1	7.9	2.3	8.6	4.0	9.4	5.2	10.4	5.5	10.8	5.2	11.3	5.1	12.2	4.1	11.9	3.6	11.4	3.3	11.3
Successful retrievals																				
High frequency	1.5	6.5	2.0	6.8	2.5	7.4	2.5	7.7	2.0	7.5	1.1	6.0	0.8	4.7	0.4	5.0	1.0	5.1	1.1	5.3
Low frequency	3.7	12.2	4.1	11.4	4.7	12.7	4.4	13.0	3.5	12.9	2.8	14.4	1.6	15.9	2.2	15.1	2.4	14.7	3.0	12.8
Slow retrievals																				
High frequency	1.3	8.0	2.1	8.4	3.0	8.9	3.1	8.9	2.5	9.0	1.4	6.9	0.8	5.8	0.4	5.7	1.4	6.1	1.4	6.9
Low frequency	4.0	12.5	4.4	12.1	5.4	12.9	5.3	12.9	4.1	12.8	2.8	14.8	2.0	14.9	2.2	15.2	2.4	14.7	3.2	12.3
Fast retrievals																				
High frequency	2.8	10.3	2.5	9.7	2.1	10.9	1.6	10.7	1.1	9.3	0.1	8.6	−0.2	9.3	−0.5	9.0	−0.4	8.9	0.2	8.8
Low frequency	2.5	14.3	2.1	16.6	1.5	16.4	0.7	17.5	0.8	17.3	2.0	18.3	0.2	18.1	1.6	18.3	1.6	18.8	1.6	18.3

effect of phase. Specifically, the cue-elaboration–search phase seemed to require more resources than the cue-encoding and retrieval mode phases. Table 6 also indicates an interaction between encoding–retrieval and phase showing that the difference between encoding and retrieval was greatest in the cue-elaboration–search phase. Finally, there seemed to be an effect of word frequency; that is, low-frequency words appeared to require more resources than high-frequency ones. A three-way ANOVA with attention condition (DA at encoding and at retrieval), word frequency, and phase–component as the three variables indicated

Table 6

Secondary Tracking Task Means for the Different Phases of the Encoding and Retrieval Segments of High-Frequency and Low-Frequency Words (Distance in Millimeters): Experiment 2

Encoding/retrieval types	Phase					
	Cue encoding[a]		Cue elaboration–search[b]		Mode	
	M	*SD*	*M*	*SD*	*M*	*SD*
Encoding						
High frequency	1.37	5.4	1.64	6.1	1.26	6.0
Low frequency	2.01	7.0	2.35	6.9	3.05	7.0
Retrieval						
High frequency	1.52	6.2	2.43	7.0	1.16	5.5
Low frequency	3.29	10.1	4.45	11.0	3.28	11.8
Successful retrievals						
High frequency	1.51	6.5	2.38	7.1	0.81	4.5
Low frequency	3.67	12.2	4.38	12.2	2.27	13.8
Unsuccessful retrievals						
High frequency	1.91	9.1	3.25	10.1	2.79	9.9
Low frequency	2.23	9.2	4.22	10.8	5.40	13.4
Slow retrievals						
High frequency	1.35	8.0	2.70	8.3	1.03	5.4
Low frequency	3.99	12.5	5.01	12.5	2.38	13.6
Fast retrievals						
High frequency	2.80	10.3	2.10	9.8	−0.27	8.0
Low frequency	2.46	14.3	1.46	14.8	1.38	17.2

[a] For encoding: pair encoding (see text). [b] For encoding: encoding period (see text).

no significant effect of encoding versus retrieval, $F < 1.0$; a significant effect of word frequency, $F(1, 64) = 4.87$, $p < .05$, $MSE = 92.51$; and a significant effect of phase–component, $F(2, 128) = 4.67$, $p < .05$, $MSE = 6.42$. Follow-up analyses showed that the significant effect of phase–component was due to the larger resources required in the cue-elaboration–search phase than in the cue-encoding and mode phases, $F(1, 64) = 8.83$, $p < .05$, $MSE = 6.14$, and $F(1, 64) = 5.13$, $p < .05$, $MSE = 6.50$, respectively. The only significant interaction was that of encoding–retrieval and phase–component, $F(2, 128) = 7.19$, $p < .01$, $MSE = 4.00$. Several follow-up analyses were performed on this significant interaction. Analysis of simple effects of phase–component for encoding indicated no significant differences, $F(2, 128) = 1.42$, *ns*, $MSE = 4.94$. A similar analysis for retrieval indicated significant differences, $F(2, 128) = 9.44$, $p < .01$, $MSE = 5.48$. Follow-up comparisons for retrieval indicated that the distance measure was larger in the cue-elaboration–search phase than in the cue-encoding and retrieval mode phases, $F(1, 64) = 12.26$, $p < .01$, $MSE = 5.21$, and $F(1, 64) = 12.95$, $p < .01$, $MSE = 6.90$, respectively. The latter two were not different from each other, $F < 1.0$. These results replicated those obtained in Experiment 1.

One further analysis, relevant to subsequent analyses, was performed to compare the attentional costs associated with the retrieval of high-frequency and low-frequency words. This analysis yielded an effect that approached significance, $F(1, 64) = 3.92$, $p = .05$, $MSE = 101.62$, with low-frequency words resulting in larger distance measures ($M = 3.69$) than high-frequency ones ($M = 1.68$).

The preceding results indicate, as discussed in the introduction and in the discussion of Experiment 1, that in contrast to the results reported in Experiment 2 by Naveh-Benjamin et al. (1998) for a free-recall task, which indicated a uniform cost throughout the retrieval period, there is an attentional cost associated with specific retrievals, a cost that a free-recall task may have masked. When a cued-recall task, which enables the separation of specific phases at retrieval, is used, there seem to be extra attentional costs associated with cue-elaboration–search processes for a particular target. This pattern is obtained for both high- and low-frequency words.

Successful versus unsuccessful retrievals. To specify the attentional costs associated with unsuccessful retrievals, we separated, as in Experiment 1, those trials in which participants provided no retrieved response (unsuccessful retrievals) from those in which a retrieved response was given (successful retrievals, since, as in Experiment 1, in 95% of the cases in which a word was retrieved, it was the correct one, and thus we took all trials in which a response was given to indicate successful retrievals).

Table 5 presents secondary task tracking performance averaged across all participants (distance in millimeters) for the aggregated 5-s successful and unsuccessful retrieval segments, for low- and high-frequency words separately, after single-task tracking performance had been subtracted. To analyze the attentional costs associated with different phases of the retrieval period for successful and unsuccessful retrievals, we broke down the 5-s retrieval period into three components (cue encoding, cue elaboration–search, and retrieval mode), as in Experiment 1. The resultant means appear in Table 6.

A three-way ANOVA with retrieval type, word frequency, and phase–component as variables indicated that although unsuccessful retrievals resulted in larger distance measures ($M = 3.02$) than successful ones ($M = 2.49$), this difference was not statistically significant, $F < 1.0$. Both types of retrieval required attentional resources for their execution, as reflected by the distance measure being significantly larger than 0.0 mm, $ts(64) = 3.16$ and 2.38 for unsuccessful and successful retrievals, respectively, $ps < .05$. In addition, the effect of component–phase was significant, $F(2, 128) = 5.49$, $p < .01$, $MSE = 16.15$. Finally, the effect of word frequency was not significant, $F(1, 64) = 1.79$, *ns*, $MSE = 208.3$.

One clarification is necessary regarding the lack of a frequency effect obtained in this analysis. As noted, earlier analysis of overall retrieval costs indicated greater costs for low-frequency than for high-frequency words. One possible reason for this discrepancy is the different ways in which the measures were computed in each analysis. When overall retrieval costs were assessed for low-frequency words, they reflected the fact that there were significantly more unsuccessful retrievals for these words than for their high-frequency counterparts (see Table 4 and the memory analysis described earlier, which indicate significantly higher percentages of unsuccessful retrievals for low-frequency words). As a result, the somewhat larger costs of unsuccessful retrievals were weighted more for low- than for high-frequency words. High-frequency words are characterized by more successful retrievals that require fewer resources. This results in overall larger attentional costs for low-frequency words, as reported earlier (Table 5). Separate analysis of successful and unsuccessful retrievals allowed us to compare the aggregated segment for each type of retrieval, and hence each was weighted equally for low- and high-frequency words. The lack of a word frequency effect in terms of associated attentional costs at retrieval reported here indicates that each type of retrieval separately (either successful or unsuccessful) requires the same amount of resources for its execution, regardless of whether the words are low- or high-frequency ones.

Most important, the interaction of type of retrieval and component–phase was significant, $F(2, 128) = 10.07$, $p < .01$, $MSE = 11.94$. Several follow-up analyses were performed. Analysis of interaction comparisons for the cue-encoding and cue-elaboration–search phases indicated, as in Experiment 1, a significant increase in the distance tracking measure from the cue-encoding to the cue-elaboration–search phase, $F(1, 64) = 15.31$, $p < .01$, $MSE = 10.64$, but no significant interaction with retrieval type, $F(1, 64) = 2.81$, *ns*, $MSE = 6.65$. This suggests a significant increase in attentional resources when moving from the cue-encoding to the cue-elaboration–search phase for both successful and unsuccessful retrievals. Analysis of interaction comparisons for the cue-elaboration–search and retrieval mode phases indicated a significant interaction with retrieval type, $F(1, 64) = 9.58$, $p < .01$, $MSE = 11.97$. Further contrast comparisons showed that whereas there was a significant decrease in the distance measure from the second to the third phase for successful retrievals, $F(1, 64) = 14.98$, $p < .01$, $MSE = 13.89$, there were no significant differences between these two phases for unsuccessful retrievals, $F(1, 64) < 1.0$, *ns*, $MSE = 16.03$. This was the case for both high- and low-frequency words. Finally, analysis of interaction comparisons for the cue-encoding and retrieval mode phases indicated a significant interaction with retrieval type, $F(1, 64) = 13.24$, $p < .01$, $MSE = 17.08$. Further contrast comparisons showed that whereas unsuccessful retrievals involved a significant increase in the distance measure from the first to the third phase, F(1,

64) = 6.00, $p < .05$, $MSE = 27.35$, successful retrievals involved a significant decrease from the first to the third stage, $F(1, 64) = 7.47$, $p < .01$, $MSE = 9.58$. This last result may suggest that greater attentional resources are required for cue encoding than for the retrieval mode, because only in successful retrievals can the retrieval mode be assessed separately. In unsuccessful retrievals, the designated retrieval mode reflects, at least to some degree, the continuation of cue-elaboration–search processes.

In general, these analyses, much like those reported in Experiment 1, reveal a substantial increase in attentional resources associated with cue-elaboration–search processes, along with a decrease in these resources once a retrieval is successful. For unsuccessful retrievals, participants' continuous search for the target was associated with substantial attentional resources being required after cue encoding and throughout the retrieval period. Interestingly, these patterns characterize both low- and high-frequency words. The different phases of retrieval of low- and high-frequency words seem to be similar in terms of the attentional costs required. The attentional resources associated with the cue-encoding phase, which can be estimated by comparing tracking performance during this phase with tracking performance during the retrieval mode phase for successful retrievals only (in the case of unsuccessful retrievals, the attentional costs during the designated retrieval mode phase may reflect continuous target search), seem to exceed those required by the retrieval mode phase.

Fast versus slow retrievals. To assess potential differences among the successful retrievals, we split them, as in Experiment 1, into two groups: fast retrievals, comprising retrievals with response latencies of 1,400 ms or less (M = 1,125 ms), and slow retrievals, comprising retrievals with response latencies above 1,400 ms (M = 2,356 ms). This resulted in 23% of all successful retrievals being fast and 77% slow.

To assess attentional costs required by the slow and fast retrievals, we split the distance measure reported earlier for successful retrievals, separately examining fast and slow ones. We created two aggregated retrieval segments, one with the retrieval response at approximately 1,100 ms (for fast retrievals) and the other with the retrieval response at approximately 2,400 ms (for slow retrievals), using the same procedures used in Experiment 1.

Each participant's tracking performance was, as before, averaged across the four DA at retrieval trials after baseline performance every 20 ms had been subtracted. Figure 4 and Table 5 present the secondary task tracking performance (distance in millimeters) of the aggregated 5-s fast and slow successful retrieval segments averaged across participants and word frequency (the unsuccessful retrievals and the encoding segments were added to Figure 4 for purposes of comparison with the successful retrievals). This secondary task performance represented the overall temporal distribution of attentional costs associated with encoding and with each type of retrieval.

Inspection of Figure 4 reveals different patterns for fast and slow retrievals. Mean secondary task distance was larger for slow retrievals (2.68 mm) than for fast ones (1.20 mm), $t(64) = 1.97$, $p < .05$. In this experiment, only the slow retrievals required attentional resources for their execution, as reflected by the distance measure being significantly larger than 0.0, $t(64) = 2.48$, $p < .05$. The fast retrievals did not require attentional resources for their execution, as shown by the distance measure for these retrievals not being significantly larger than 0.0, $t(64) = 0.90$, *ns*.

To assess changes in attentional resources for slow and fast retrievals over the retrieval period, and to analyze the attentional costs associated with different phases of the retrieval process for each word frequency, we broke the 5-s retrieval interval into the three components mentioned earlier (cue encoding, cue elaboration–search, and retrieval mode). The resultant means appear in Table 6 and Figure 5.

Inspection of Table 6 and Figure 5 indicates that slow retrievals resulted in a larger tracking distance measure than fast ones. Also,

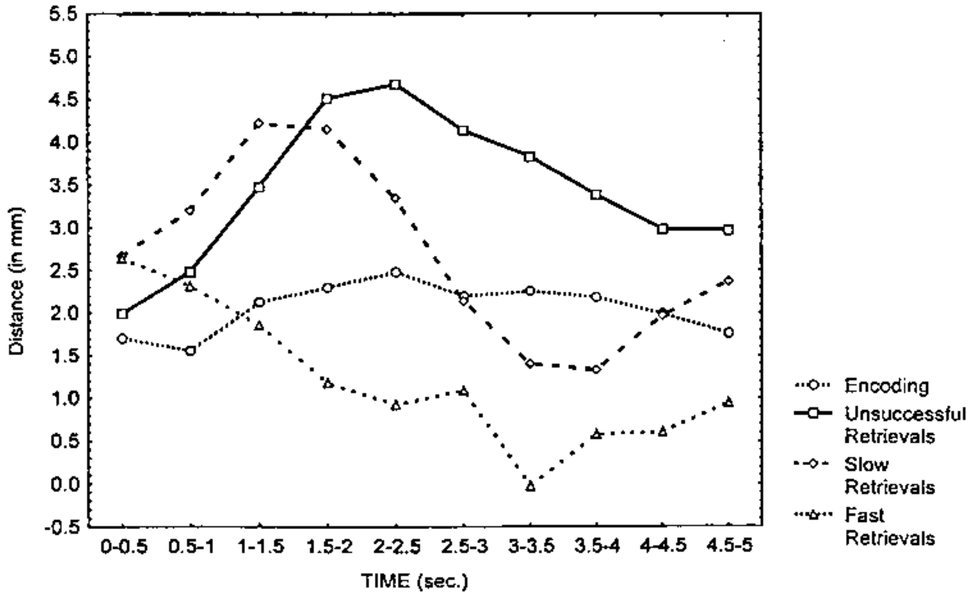

Figure 4. Temporal distribution of performance on the secondary tracking task for the aggregated 5-s encoding, unsuccessful retrieval, slow retrieval, and fast retrieval segments after single-task tracking performance subtraction (distance in millimeters): Experiment 2.

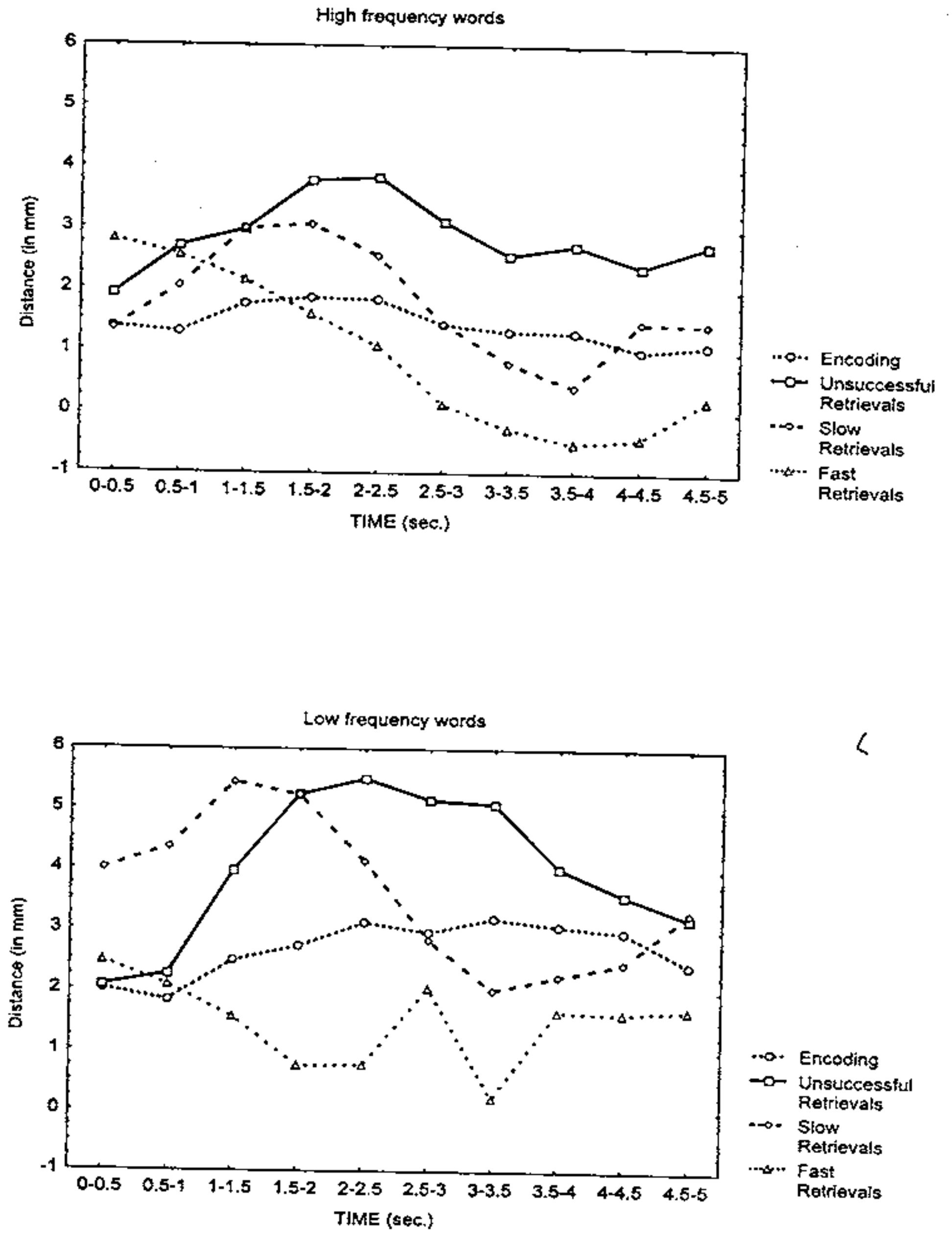

Figure 5. Temporal distribution of performance on the secondary tracking task for the aggregated 5-s encoding, unsuccessful retrieval, slow retrieval, and fast retrieval segments after single-task tracking performance subtraction (distance in millimeters) for high-frequency and low-frequency words: Experiment 2.

the retrieval mode phase seemed to result in smaller tracking distances than the cue-elaboration–search phase. Finally, there seemed to be an interaction between retrieval type and phase. A three-way ANOVA with word frequency, retrieval type, and phase–component as variables indicated no effect of word frequency, $F < 1.0$, or retrieval type, $F(1, 64) = 2.11$, $MSE = 108.97$, and a significant effect of phase–component, $F(2, 128) = 9.70$, $p < .01$, $MSE = 23.23$. The lack of an effect of retrieval type (slow vs. fast) does not contradict the reported overall larger attentional costs associated with slow retrievals mentioned earlier. Note that the componential analysis weighed each component to the same degree regardless of the number of data points that contributed to the component. For example, cue encoding, which was based on only one data point (0–500 ms), had the same weight as the retrieval mode component, although the latter was based on four data points (2.5–3 to 4.0–4.5 s). As a result, such an analysis could produce findings differing somewhat (although not in the patterns obtained) from those based on all data points, as was the case in the comparison of overall costs associated with slow and fast retrievals.

Most important, the interaction between retrieval type and phase–component was significant, $F(2, 128) = 5.31$, $p < .01$,

$MSE = 12.76$. Several follow-up analyses were performed on the significant interaction. An analysis of interaction comparisons with cue-encoding and cue-elaboration–search phases and fast and slow retrievals showed a significant interaction, $F(1, 64) = 14.57$, $p < .01$, $MSE = 9.28$. Further contrast comparisons showed that whereas there was no difference between slow and fast retrievals in the cue-encoding phase, $F(1, 64) < 1.0$, *ns*, $MSE = 39.23$, there was a significant difference between the two retrieval types in the cue–elaboration–search phase, $F(1, 64) = 5.56$, $p < .05$, $MSE = 50.31$, in which slow retrievals were associated with larger tracking distances (more attentional resources).

The different patterns of the distance measure in the cue-encoding and cue-elaboration–search components for slow and fast retrievals were also apparent when contrasts were used to compare phases within each type of retrieval. For slow retrievals, the contrast comparing the cue-encoding and cue-elaboration–search phases was significant, $F(1, 64) = 13.67$, $p < .01$, $MSE = 6.70$, indicating an increase in the distance measure; for fast retrievals, the same contrast was nonsignificant, $F(1, 64) = 2.92$, *ns*, $MSE = 16.17$, and in the opposite direction.

Analysis of interaction comparisons with cue-elaboration–search and retrieval mode phases for slow and fast retrievals indicated a significant decrease in the distance measure when moving from the cue-elaboration–search phase to the retrieval mode phase, $F(1, 64) = 11.72$, $p < .01$, $MSE = 31.67$. However, there was not a significant interaction, $F(1, 64) = 2.43$, *ns*, $MSE = 11.38$.

Altogether, these analyses reveal, as did the results of Experiment 1, that slow retrievals are associated with a substantial increase in attentional resources during cue-elaboration–search processes, accompanied by a decrease in these resources once a retrieval is successful. By contrast, fast retrievals, if anything, are associated with a decrease in attentional resources during the cue-elaboration–search phase. These patterns characterized both low-frequency and high-frequency words.

Overall, the results of Experiment 2 reveal patterns similar to those reported in Experiment 1. In particular, DA at encoding, but not at retrieval, affected memory performance. In addition, retrieval latency was slowed to the same degree under both DA at encoding and DA at retrieval (relative to full attention). Also, the attentional costs associated with retrieval were mostly related to the time after the cue was encoded and before a retrieval response was initiated. Successful retrievals show this pattern until a retrieval response is produced, whereas unsuccessful retrievals show it throughout the retrieval period until the next cue is presented. Finally, successful retrievals appear in two distinct varieties: slow and fast. Whereas the former are associated with increases in resources during the cue-elaboration–search phase, the latter show no increases in resources associated with search for the target.

The manipulation of word frequency yielded results similar to those obtained by Naveh-Benjamin et al. (1998, Experiment 1), showing, again, the resilience of retrieval processes to the effects of DA: Even when more difficult material had to be retrieved (as is the case with low-frequency words; Gregg, 1976), it was not affected by a division of attention at retrieval. With respect to the effect of word frequency on retrieval latency, low-frequency words were retrieved at a slower pace than high-frequency ones. In addition, both types of words were slowed to the same degree when attention was divided either at encoding or at retrieval. Finally, this experiment indicates that the extra overall attentional costs shown by Naveh-Benjamin et al. (1998) to be associated with low- versus high-frequency words are due, at least in part, to the different proportions of retrieval types involved in the retrieval of each word type. Specifically, the overall larger attentional costs associated with low-frequency words are apparently partially due, first, to the larger proportion of unsuccessful retrievals of these words (41%, as compared with 28% for high-frequency words, $t(64) = 5.25$, $p < .01$, retrievals that consume more resources than successful ones, and second, to the larger proportion of slow retrievals for these words (80% of all successful retrievals vs. 73% for high-frequency words), $t(64) = 3.24$, $p < .01$, which consume more resources than fast ones. Interestingly, the costs associated with each type of retrieval and with each phase of retrieval were not different for high- and low-frequency words, even though Figure 5 seems to imply an overall rise in the encoding and retrieval costs of low-frequency words relative to high-frequency ones. Although the statistical tests were far from being significant ($F < 1$), possible cost differences between high- and low-frequency words were perhaps being obscured by the relative smaller number of observations used in the analysis of retrieval phases and retrieval components (see General Discussion).

General Discussion

The results of the two present experiments provide converging evidence for results reported in the past and, at the same time, supply novel information regarding the effects of DA on encoding and retrieval processes and the attentional costs associated with these processes. To summarize our major findings, the current experiments replicated previous results (e.g., Craik et al., 1996; Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000; Naveh-Benjamin et al., 1998; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000) showing an asymmetry between encoding and retrieval processes under the effects of DA: Whereas division of attention at encoding significantly downgrades memory performance, division of attention at retrieval has almost no effect on memory performance. In the current study, this was demonstrated with a tracking task serving as the secondary task and cued recall serving as the memory task. This protection of retrieval processes, however, required substantial attentional resources, as reflected by performance on the secondary tracking task. The resources required during retrieval were either the same as (Experiment 2) or larger than (Experiment 1) those required during encoding. The different patterns of encoding–retrieval resource consumption in the two experiments mimic those reported in the literature. Whereas some studies (e.g., Craik et al., 1996, Experiments 1 and 2; Naveh-Benjamin et al., 1998) show retrieval to require more overall resources than encoding, others (Craik et al., 1996, Experiment 3; Naveh-Benjamin et al., 1998, Experiment 2; Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000) show substantial but equal resources required by the two.

It may be that one determinant of the resources required at retrieval is the nature of the secondary task. It is possible that secondary task costs reflect the attentional resources required to manage simultaneous memory and secondary task operations and that retrieval is more sensitive than encoding to an increase in the complexity of these joint processing operations. Although we used tracking tasks in both experiments, they were somewhat different.

Experiment 1 involved more uncertainty, in that the asterisk could move in any direction. In Experiment 2, on the other hand, the asterisk's movement involved less uncertainty in that it followed a predesignated circular path. Thus, it is possible that the relatively greater secondary task costs for DA at retrieval in Experiment 1 were a result of the combination of a moderately demanding retrieval paradigm and a relatively demanding secondary task.

Phases of Retrieval

A major purpose of the research reported here was to further assess the attentional costs associated with retrieval. To do so, we used a cued-recall task that, unlike the free-recall task used by Naveh-Benjamin et al. (1998), enables one to separate the attentional resources required. We designated three retrieval phases or subcomponents—cue encoding, cue-elaboration–search processes for a specific word, and the operation of a retrieval mode—by separating each retrieval interval into three phases and evaluating the gradient of attention required with each. The first phase included the period preceding the end of the presentation of the cue, which presumably reflected mostly cue-encoding operations. The second phase, which reflects cue-elaboration–search processes, extends from the point at which a given cue is provided to the participant until she or he furnishes a retrieved response. The demand for resources associated with cue-elaboration–search processes was differentiated from consumption of resources by a retrieval mode that could be evaluated during the period following a retrieval and before the next cue was presented. During this period, the participants were in a cognitive mode of being ready to retrieve without a specific cue directing them to search for a particular target. For comparison purposes, the same time periods were designated to encoding. The secondary tracking tasks gave us the precise microlevel measurement of those resources devoted to encoding and retrieval every 20 ms.

The results of both experiments indicate, in contrast to previous studies, that retrieval, at least during a cued-recall task, does not require uniform attentional resources. The first phase of cue encoding requires some resources, much like the requirement for resources by stimuli detection at encoding. In Experiment 2, there appeared to be a cost associated with the cue-encoding phase that significantly exceeded the one associated with the retrieval mode phase (see the Results section of Experiment 2). The second phase, involving cue-elaboration–search processes, required substantial resources for its execution. This was manifested in two ways. First, for successful retrievals, the period after cue encoding and before the retrieved response was associated with poorer performance on the secondary task (larger tracking distance) than either the respective period at encoding or the retrieval period following the retrieval response. Second, the use of a cued-recall task allowed us to measure attentional resources associated with both successful and unsuccessful retrievals. Performance on the secondary task for unsuccessful retrievals (in which no retrieved response was provided by the participant) was poor throughout the retrieval period of a given target. Specifically, whereas unsuccessful retrievals consume attentional resources for their execution, as successful retrievals do, up to the point of the retrieved response, these unsuccessful retrievals continue to require resources for the whole retrieval period, presumably reflecting the continuation of cue-elaboration–search processes.

In addition, it seems that being in a retrieval state of mind that operates in the background (retrieval mode) also requires attentional resources, although not as many as required by cue elaboration–search. This cost can be evaluated by looking at successful retrievals after their completion, a period during which participants were not trying to retrieve a given word (they did not know which cue would be presented next). Although the secondary task indicated better performance (fewer attentional resources required) than during the previous cue-elaboration–search period, costs were still substantial, above and beyond those required in the secondary task baseline condition. These larger costs during the retrieval mode phase than during the matched baseline period probably rule out general alertness as the sole underlying cause, because participants presumably were also alert during all of the baseline trials.

Types of Retrieval

The similarities and differences characterizing successful and unsuccessful retrievals are compatible with a componential view. Both require the same amount of attentional resources for the execution of the cue-encoding and cue-elaboration phases; after these phases, however, the pattern of their attentional cost diverges. Successful retrievals (in which the retrieval response terminates the cue-elaboration–search phase, moving participants to a retrieval mode phase) are associated with fewer attentional resources, whereas unsuccessful retrievals (in which the cue-elaboration–search phase proceeds until the next cue is presented) are associated with continuous large attentional costs. Note that we have not considered retrievals that were completed erroneously (i.e., participants provided the incorrect target), because few such errors occurred in the current study. Future use of a recognition memory task in which false alarms are inspected could provide information regarding the attentional costs associated with this type of retrieval.

Another question addressed in the current study concerned the existence of different types of successful retrievals. We wanted to find out whether different types of retrievals can be distinguished and their associated attentional costs measured. By using a measure of retrieval latency, we distinguished slow from fast retrievals and estimated the attentional resources associated with each. Results of both experiments indicated that these two types of retrievals require different amounts of resources for their execution. Slow retrievals were associated with substantial attentional resources, especially during the cue-elaboration–search phase. Fast retrievals, however (characterized by a retrieval response within less than 1 s after the cue had been presented), which constituted about 25% of all successful retrievals, required fewer resources for their execution (in Experiment 2, they did not require extra resources beyond the secondary task baseline condition) and, in particular, did not seem to show an increase in required attentional resources during the cue-elaboration–search phase. One interpretation of these results is that fast retrievals bypass and do not require cue-elaboration–search processes. In this sense, the current work suggests the operation of two qualitatively different types of successful retrievals: one that is fast and requires few attentional resources for its completion (automatic) and one that is slower and requires substantial resources (strategic). Note that the retrieval latency and secondary task performance measurements were independent of each other. Fast retrievals could therefore theoretically require less, more, or the same amount of attentional resources as their slower counterparts.

As mentioned in the introduction, identification of two types of successful retrieval is in line with several suggestions in the literature that the retrieval process is not unitary and that different retrievals may be based on different mechanisms. For example, Jacoby (1991) distinguished automatic retrievals based on familiarity from controlled ones based on recollection. Gardiner and Java (1993) distinguished retrievals based on recollective experience (*remember responses*) from retrievals based on familiarity only (*know responses*). Although Jacoby and Gardiner and Java used these terms mostly within the context of a recognition paradigm, it seems plausible that the fast retrievals we witnessed could be related to those retrievals that are automatic, according to Jacoby (although controlled retrieval also can be faster, as well), or based on familiarity, according to Gardiner and Java. Our slow retrievals may be related to those retrievals termed controlled by Jacoby or to those based on remember responses, as suggested by Gardiner and Java. Future research should address this apparent similarity. Note that whereas the distinction between controlled and automatic retrievals made by Jacoby and Gardiner and Java is based on subjective responses by participants, our current results add to this distinction by providing objective indexes of latency and resources associated with each type of retrieval.

Another suggestion related to the cued-recall task used in the current study is the one made by Jacoby (1998) and Guynn and McDaniel (1999), namely, that recall can be accomplished in two ways: either through the generate and recognize route or via direct retrievals. It is conceivable that the slow retrievals identified in the current study reflect those retrievals that are carried out via the generate–recognize route, whereas the fast retrievals identified may reflect the use of information from encoding during recall to access target information directly. Finally, a further relevant distinction is the one made in the skill acquisition literature between one-step retrievals and those based on algorithms, with the former characterized by fast responses and the latter characterized by extensive computation (Logan, 1988; Tzelgov, Yehene, & Naveh-Benjamin, 1997).

The underlying sources of these different types of successful retrievals have yet to be determined. One possibility is that fast and slow retrievals reflect differences in the ease with which certain word pairs can be retrieved. The results of Experiment 2, which indicated larger proportions of fast retrievals in the high-frequency than the low-frequency words, are consistent with this possibility. Another possibility is that these types of retrieval are related to individual differences in preexperimental associative structure; it may be that the fast retrievals made by a given individual include those word pairs that are strongly associated preexperimentally, whereas slow retrievals reflect word pairs that are not associated in this manner. A further possibility is that a fast retrieval may reflect an adequate episodic binding of a given word pair created by the participant during encoding. One potential prediction is that manipulations that enhance the creation of episodic binding at encoding will result in a larger proportion of fast retrievals. Assuming that frequent words could better be bound together, the results of Experiment 2, which indicate significantly larger proportions of fast retrievals for high-frequency than low-frequency words, are consistent with this possibility. Finally, although we attempted a range of retrieval latency splits for fast and slow retrievals (see Footnote 3), all of which resulted in patterns similar to those reported earlier, we cannot rule out the possibility of a whole "family" of curves, ranging from fast to slow retrievals, that are associated with an increase in attentional costs.

Use of a Multimeasure Approach

Measuring retrieval latency as well as retrieval accuracy to assess the effects of DA at encoding and retrieval on both measures could also provide a more comprehensive picture of performance. Whereas Baddeley et al. (1984) and Carrier and Pashler (1995) demonstrated a slowdown of retrieval responses under DA during retrieval, they did not consider the effects of DA at encoding on retrieval latency. As mentioned earlier, one interesting question is whether division of attention during encoding, as in the case of retrieval (e.g., Baddeley et al., 1984), will lead to delay in retrieval responses even though no bottleneck is involved, as could be the case when attention is divided at retrieval. The results from both experiments of the current study show a significant slowdown in retrieval latency at encoding and at retrieval relative to retrieval latency in the full attention condition. These results suggest that there may be several factors that influence retrieval latency. Although retrieval bottleneck can accommodate slowdown during retrieval, it can hardly explain slowdown in retrieval when attention was divided at encoding. In the latter case, this slowdown may reflect poorer memory trace due to the interference of DA at encoding, resulting in both poorer memory and slower retrievals. By contrast, DA at retrieval seems to slow down responses but not to interrupt retrieval, because memory performance was no worse under DA at retrieval than under full attention.

Overall, the current results suggest that a thorough investigation of encoding and retrieval processes should involve several measures of performance that allow, separately and in combination, the uncovering of different facets and components of these processes. Whereas previous studies involved either a one-measure approach (e.g., Murdock, 1965, only accuracy; Johnston et al., 1970, only overall attentional costs; Carrier & Pashler, 1995, only latency) or a two-measure approach (e.g., Baddeley et al., 1984, accuracy and latency; Craik et al., 1996, and Naveh-Benjamin et al., 1998, accuracy and attentional costs), we advocate the use of a multimeasure approach. In the current study, we used four measures of performance: memory accuracy, retrieval latency, overall attentional costs, and the temporal distribution of attentional costs. We believe that such an approach, the usefulness of which was demonstrated here, provides a more comprehensive perspective on the phenomenon under investigation. In particular, the introduction of on-line temporal measurements of a specific pattern of behavior could help researchers in reaching conclusions regarding characteristic processes that, in combination, yield that behavior.

One demonstration of the usefulness of such a multimeasure approach is the set of results obtained in Experiment 2, which compared the encoding and retrieval of low-frequency and high-frequency words. Using the combination of retrieval latency and temporal distribution of attentional costs, we were able to show that the overall larger attentional costs associated with low-frequency words, as reported in Experiment 1 of Naveh-Benjamin et al. (1998) and replicated in the current Experiment 2, are due, at least in part, to differences in the proportions of retrieval types associated with word frequency. In particular, the greater overall attentional costs associated with low-frequency words are related, at least in part, to the fact that these words are characterized by both more unsuccessful retrievals and more slow but successful retrievals than high-frequency words. These unsuccessful and slow retrievals require more attentional resources, leading to greater overall attentional costs for low-frequency words. The costs associated with each type of retrieval (unsuccessful, slow, and fast) for high- and low-frequency words, however, were not significantly different. A tentative conclusion is that the operation of each type of retrieval and each retrieval phase may be associated with a fixed, predetermined attentional cost. What may differentiate the attentional costs associated with the retrieval of different materials, different individuals, or different encoding conditions is the proportion of different retrieval types used in each particular case, which contribute to overall attentional costs. Of course, such an atomistic view of invariant retrieval processes that, in combination, characterize a retrieval behavior needs further research. A complementary account supported by the pattern of results obtained, though not statistically significant, is based on the fact that the temporal distribution of the different types of retrieval seems to be similar for high- and low-frequency words, with only overall costs being higher for low-frequency words (see Figure 5). Such a pattern may indicate that although the component processes seem to be similar, there may be an extra attentional cost associated with low-frequency words, presumably reflecting a higher retrieval mode cost.

The current approach is related to a line of research on retrieval processes that has attempted to unveil the dynamics of memory retrieval. Several studies (e.g., Dosher, 1981; Hintzman & Caulton, 1997; Hintzman & Curran, 1994; McElree & Dosher, 1993) have used one variation or another on the response-signal method to determine how the retrieval of a single item or event unfolds over time. With this method, the amount of time available for retrieval is varied, and memory accuracy is plotted as a function of increase in processing time. The results of these studies indicate different dynamics for different memory tasks (e.g., item memory and modality judgments [Hintzman & Caulton, 1997], item memory judgments and frequency judgments [Hintzman & Curran, 1994], and item information and order information [McElree & Dosher, 1993]. In addition, these studies have shown an interaction of preexperimental and experimental associations in the dynamics of episodic and semantic memory judgments (Dosher, 1984; Dosher & Rosedale, 1991).

Although the studies reported here were run within a different research context and for a different purpose, and although we used a cued-recall procedure rather than one based on recognition, it seems that our approach and those of the studies just mentioned have some common aspects. In particular, whereas the response-signal procedure focuses on the time-related dynamics of memory accuracy, the current studies focused on the dynamics of the attentional resources associated with memory accuracy. It may be interesting to find out whether the different patterns of retrieval dynamics established for different memory tasks within the response-signal procedure also show different attentional patterns. For example, would the retrieval of modality information, which seems to be delayed relative to item information under the response-signal procedure, be associated with a longer and more resource-demanding cue-elaboration–search process? Likewise, are the fast retrievals identified in the current study, which seem to consume few attentional resources, associated with the point at which accuracy first rises above chance in the response-signal procedure?

Taxonomy of Retrieval Subcomponents

One issue addressed in this research is related to the assessment and localization of the larger secondary task costs associated with the protection of memory retrieval and the identification of the subprocesses at retrieval (and at encoding) that involve these attentional resources. One theoretical framework that may help in outlining the taxonomy of possible subprocesses has been advanced by Tulving (1983), who claimed that explicit retrieval is assumed to first involve entering a retrieval mode, "when the system is set for treating events as cues to stored episodes" (Tulving, 1983, p. 170). As mentioned earlier, this may involve the downloading of retrieval procedures from long-term memory to working memory, where they are held during the retrieval period and hence may tax the attentional resources of the system. The results of the current experiments, which show a substantial cost associated with successful retrievals after a target was retrieved and before the next cue was presented, may reflect the attentional resources associated with maintaining a retrieval mode. The nature of this mode is left open, however, and the current results cannot specify whether this cost is related specifically to the retrieval phase or is simply a reflection of a general mental preparatory state. The latter possibility is not supported by results from the Naveh-Benjamin et al. (1998) study, which indicated that secondary task costs associated with general readiness for the appearance of stimuli were minimal. Also, note the differences between slow and fast retrievals in the retrieval mode phase. These larger post-retrieval costs of slow retrievals than fast retrievals may represent a carryover effect, a kind of "cognitive inertia" carried over from the greater effort required for slow retrievals. Alternatively, such costs may represent a postretrieval check for these hard-to-retrieve items. As the preceding discussion shows, any theory of retrieval should define better the concept of retrieval mode, allowing researchers to measure this aspect of retrieval more accurately.

The second component of such a retrieval mechanism may be cue elaboration (e.g., Tulving, 1983). This process involves using either external or internal cues to initiate a search for other cues that terminates once enough cue information is available, allowing the ecphory process to take place. Such a process is thought to require appreciable attentional resources. The results of the current study indicate that substantial attentional resources are associated with the period when participants try to elaborate on the cue and search their memory for candidate targets. These costs are reflected both in slow but successful retrievals, until a response is retrieved, and in unsuccessful retrievals throughout the retrieval period.

Finally, a third component suggested to be involved in retrieval is ecphory, which is the process associated with the successful recovery of stored information (Moscovitch, 1992; Tulving, 1983). Ecphory is described in the literature as a process that is automatic in nature and as one that requires only minimal resources, although this remains untested empirically. The results of the current study, although not intended to directly explore this component, may shed some light on its operational mode. There are some indications that ecphory does require minimal resources. First, fast retrievals, which occur about 1,200 ms after the initiation of cue presentation, do not show any increase in associated resources from 500 to 1,200 ms, when the actual retrieval might have occurred (if anything, they show a decrease). If ecphory required resources, we would have expected to see an increase in the distance measure during this period, which we did not. Second, data from Naveh-Benjamin et al. (1998) support this notion as well. For example, the results of Experiment 1 of that study, which indicate the protection of memory performance under DA at retrieval when the retrieval cue changes perceptually from encoding and no associated increase in secondary task costs, may imply that the perceptual similarity manipulation affected the processes associated with ecphory. Also, in Experiment 2 of that study, which involved a free-recall task, there were no costs associated with the period around the retrieval point (half a second before or after the retrieval response).

Note that although the current results were interpreted within Tulving's (1983) framework, the patterns of results obtained might prove to be compatible with other approaches to memory retrieval. As mentioned earlier, one suggestion put forward regarding recall processes is that they may involve either a generation–recognition route or a direct retrieval one (Guynn & McDaniel, 1999; Jacoby, 1998). Such a view may well be compatible with the current results in several respects. First, in the case of unsuccessful retrievals, neither route was completed successfully. Second, as mentioned earlier, the distinction between slow and fast retrievals may be compatible with the generate–recognize and the direct access routes. Third, with respect to retrieval phases, the generation–recognition route seems to mostly involve the cue-elaboration–search phase, and this phase appears to be bypassed when fast retrievals are involved. Note, however, that in the case of retrievals mediated by the generate–recognize strategy, recognition was not designated as a separate phase in the current study; rather, it was conceived as part of the cue-elaboration–search phase. Finally, note that in the case of direct retrievals, accessing of target information might start earlier in the sequence, once the cue is presented, hence, it may have occurred, at least partially, during the designated cue-encoding phase in the current study.

One remark is necessary on the partition used for the encoding phase: The temporal division into different segments, as well as the use of these segments as a variable in the analysis, provides a convenient way to compare encoding and retrieval and to reduce and categorize the data. However, this could have created a somewhat arbitrary segmentation of the encoding phase. For example, the encoding processes phase may last the entire encoding period after stimulus encoding, rather than being followed by an encoding mode phase; we did not know when participants completed the encoding operations for a given pair of words. This could have been the reason for the constant attentional costs found to be allocated throughout the encoding period.

Finally, how can the results reported here be reconciled with those reported in Experiment 2 of Naveh-Benjamin et al. (1998), which showed a cost associated with specific encodings but no cost associated with specific retrievals? First, the continuous uniform cost at retrieval reported by Naveh-Benjamin et al. could be explained by the fact that in a free-recall task, unlike the cued-recall task used here, the periods between retrievals reflect a continuous search of the memory node network for some candidates for retrieval. This search may require extended continuous attention and resources. Alternatively, this cost may reflect, as claimed earlier, a failure to retrieve some items (unsuccessful retrievals), the contribution of which cannot be isolated in a free-recall task but that the current study showed to require substantial resources. Second, the lack of attentional cost associated with the period just before and after the retrieval, as reported by Naveh-Benjamin et al., might be related to the ecphory phase when actual retrieval is done; as mentioned earlier, there were indications in the current study that the period just before the act of overt retrieval is associated with lower attentional costs. Third, in contrast to the uniform costs throughout the encoding period reported in the current study, Naveh-Benjamin et al. (1998) reported (Experiment 2) substantial secondary task costs associated with the period immediately before and after the appearance of the stimulus at the encoding phase. One possible reason for these differences has to do with the differences between the materials used in both studies; in Naveh-Benjamin et al. (Experiment 2) single words, which were encoded relatively quickly, were used, showing a short surge in associated processing resources. In the current study, in which pairs of words were presented, participants had to process both the items and their relationships. This might have taken the whole 5-s period, resulting in a uniform demand for resources.

Summary

Overall, the pattern emerging from the current research extends the conclusions of our earlier research by indicating that the processes associated with encoding and retrieval are substantially different. DA at encoding interferes markedly with later memory performance, whereas DA at retrieval does so to a much lesser degree. The immunity of memory performance to the effects of DA at retrieval is offset by a cost, as measured by a concurrent task. These results extend those reported by Craik et al. (1996) and Naveh-Benjamin et al. (1998) and indicate that although retrieval processes may be "automatic," in the sense that they are relatively immune to the effects of a concurrent task and are insensitive to emphasis instructions, they are certainly not automatic in the sense that they require a small amount of attentional resources; on the contrary, they are as attention demanding as encoding processes, or even more so. The current experiments showed that this demand for attentional resources is related to whether retrieval was successful or not (greater demand in the latter) and whether it was fast or slow (greater demand in the latter). In addition, the current study indicated that this greater demand for resources is modulated by the retrieval phase, in which cue-elaboration–search processes, in particular, require substantial resources for their execution. In contrast, encoding, at least of a word pair, showed a uniform temporal requirement for resources. Despite the clear evidence of a necessary similarity between effective encoding and retrieval processes, the present results provide additional evidence for the conclusion that encoding and retrieval also differ in some fundamental respects.

References

Anderson, N. D., Craik, F. I. M., & Naveh-Benjamin, M. (1998). The attentional demands of encoding and retrieval in younger and older adults: I. Evidence from divided attention costs. *Psychology and Aging, 13,* 405–423.

Baddeley, A. D., Lewis, V., Eldridge, M., & Thomson, N. (1984). Attention and retrieval from long-term memory. *Journal of Experimental Psychology: General, 113,* 518–540.

Balgur, R. (1968). *List of basic words for school.* Tel Aviv, Israel: Otsar Hamoreh.

Carrier, M. L., & Pashler, H. (1995). Attentional limits in memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 1339–1348.

Craik, F. I. M., Govoni, R., Naveh-Benjamin, M., & Anderson, N. D. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology: General, 125,* 159–180.

Craik, F. I. M., Naveh-Benjamin, M., & Anderson, N. D. (1998). Encoding and retrieval processes: Similarities and differences. In M. A. Conway, S. E. Gathercole, & C. Cornoldi (Eds.), *Theories of memory II* (pp. 61–86). Mahwah, NJ: Erlbaum.

Dosher, B. A. (1981). The effects of delay and interference: A speed-accuracy study. *Cognitive Psychology, 13,* 551–582.

Dosher, B. A. (1984). Discriminating preexperimental (semantic) from learned (episodic) associations: A speed-accuracy study. *Cognitive Psychology, 16,* 519–555.

Dosher, B. A., & Rosedale, G. (1991). Judgments of semantic and episodic relatedness: Common time-course and failure of segregation. *Journal of Memory and Language, 30,* 125–160.

Gardiner, J. M., & Java, R. I. (1993). Recognizing and remembering. In A. F. Collins, S. E. Gathercole, M. A. Conway, & P. E. Morris (Eds.), *Theories of memory* (pp. 163–188). Hove, England: Erlbaum.

Gregg, V. H. (1976). Word frequency, recognition and recall. In J. Brown (Ed.), *Recall and recognition.* Chichester, England: Wiley.

Griffith, D. (1976). The attentional demands of mnemonic control processes. *Memory & Cognition, 4,* 103–108.

Guynn, M. J., & McDaniel, M. A. (1999). Generate—Sometimes recognize, sometimes not. *Journal of Memory and Language, 41,* 398–415.

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General, 108,* 356–388.

Hintzman, D. L., & Caulton, D. A. (1997). Recognition memory and modality judgments: A comparison of retrieval dynamics. *Journal of Memory and Language, 37,* 1–23.

Hintzman, D. L., & Curran, T. (1994). Retrieval dynamics of recognition and frequency judgments: Evidence for separate processes of familiarity and recall. *Journal of Memory and Language, 33,* 1–18.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language, 30,* 513–541.

Jacoby, L. L. (1998). Invariance in automatic influences of memory: Toward a user's guide for the process-dissociation procedure. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 3–26.

Johnston, W. A., Greenberg, S. N., Fisher, R. P., & Martin, D. W. (1970). Divided attention: A vehicle for monitoring memory processes. *Journal of Experimental Psychology, 83,* 164–171.

Johnston, W. A., Griffith, D., & Wagstaff, R. R. (1972). Speed, accuracy, and ease of recall. *Journal of Verbal Learning and Verbal Behavior, 11,* 512–520.

Kolers, P. A. (1973). Remembering operations. *Memory & Cognition, 1,* 347–355.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review, 95,* 492–527.

McElree, B., & Dosher, B. A. (1993). Serial retrieval processes in the recovery of order information. *Journal of Experimental Psychology: General, 122,* 291–315.

Mishkin, M., & Appenzeller, T. (1987). The anatomy of memory. *Scientific American, 256,* 80–89.

Morris, C. D., Bransford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning and Verbal Behavior, 16,* 519–533.

Moscovitch, M. (1992). Memory and working-with-memory: A component process model based on modules and central systems. *Journal of Cognitive Neuroscience, 4,* 257–267.

Murdock, B. B., Jr. (1965). Effects of a subsidiary task on short-term memory. *British Journal of Psychology, 56,* 413–419.

Naveh-Benjamin, M. (1987). Coding of spatial location information: An automatic process? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 595–605.

Naveh-Benjamin, M. (1988). Recognition of spatial location information: Another failure to support automaticity. *Memory & Cognition, 16,* 437–445.

Naveh-Benjamin, M. (1990). Coding of temporal order information: An automatic process? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 117–126.

Naveh-Benjamin, M., Craik, F. I. M., Gavrilescu, D., & Anderson, N. D. (2000). Asymmetry between encoding and retrieval processes: Evidence from divided attention and a calibration analysis. *Memory & Cognition, 28,* 965–976.

Naveh-Benjamin, M., Craik, F. I. M., Guez, J., & Dori, H. (1998). Effects of divided attention on encoding and retrieval processes in human memory: Further support for an asymmetry. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 1091–1104.

Naveh-Benjamin, M., Craik, F. I. M., Perretta, J. G., & Tonev, S. T. (2000). The effects of divided attention on encoding and retrieval processes: The resiliency of retrieval processes. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 53*(A), 609–626.

Naveh-Benjamin, M., & Jonides, J. (1986). On the automaticity of frequency coding: Effects of competing task load, encoding strategy, and intention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 378–386.

Squire, L. R. (1992). *Memory and brain.* New York: Oxford University Press.

Tulving, E. (1983). *Elements of episodic memory.* New York: Oxford University Press.

Tzelgov, J., Yehene, V., & Naveh-Benjamin, M. (1997). From memory to automaticity and vice versa: On the relations between memory and automaticity. In J. Brzezinski, B. Krause, & T. Maruszewiski (Eds.), *Poznan studies in the philosophy of the sciences and the humanities,* (pp. 239–262). Amsterdam: Rodopi.

Received August 6, 1999
Revision received March 9, 2000
Accepted March 20, 2000 ■