16
CHAPTER

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The Attentional Demands and Attentional Control of Encoding and Retrieval

A basic question about the nature of memory encoding and retrieval concerns whether they are similar operations. Many cognitive theories champion the view that encoding and retrieval are comparable processes, such that retrieval is successful to the extent that encoding processes are reinstated (Bransford, Franks, Morris, & Stein, 1979; Craik, 1983; Kolers, 1973; Roediger, Weldon, & Challis, 1989; Tulving & Thomson, 1973). There is growing evidence, however, that these mnemonic operations differ in important ways. The divided attention paradigm has three primary advantages that make it ideally suited to address the similarity of encoding and retrieval. First, one can compare the vulnerability of encoding and retrieval to disruption by having subjects perform a secondary task only during encoding or only during retrieval. Second, one can examine the attentional control of encoding and retrieval by asking participants to vary their emphasis between the memory task and the secondary task across trials. If encoding and retrieval are under voluntary control, then as they are given more emphasis, memory performance should increase and secondary task performance should decrease. Third, one can examine the resource demands of encoding and retrieval, if secondary task costs are taken as an index of their resource demands (Kahneman, 1973; Kerr, 1973). The more central resources encoding or retrieval demand, the more they should disrupt performance on a secondary task.

The similarity and differences between encoding and retrieval in terms of their vulnerability to disruption, their attentional control, and their attentional demands will be discussed in the first three sections and summarized in the fourth section of the current chapter. These discussions will reveal that episodic encoding and retrieval are *not* similar in these regards. Episodic retrieval, in particular, is obligatory in the sense that it is relatively immune to disruption, does not operate under attentional control, but has significant attentional demands. A shared-time model of memory and current processing (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996) is described in the fourth section of this chapter, and it is shown that memory performance under conditions of divided attention at retrieval can be predicted from the amount of time theoretically available for retrieval. Finally, in the fifth section of this chapter, a new theoretical explanation of these somewhat surprising features of episodic retrieval is proposed.

☐ The Vulnerability of Encoding and Retrieval to Disruption by a Secondary Task

Divided attention during episodic encoding results in significant reductions in later memory performance (e.g., N. D. Anderson, Craik, & Naveh-Benjamin, 1998; C. M. B. Anderson & Craik, 1974; Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik et al., 1996; Murdock, 1965). By contrast, episodic retrieval is often remarkably immune to the effects of divided attention (e.g., N. D. Anderson et al., 1998; Baddeley et al., 1984; Craik et al., 1996; Kellogg, Cocklin, & Bourne, 1982; Naveh-Benjamin, Craik, Guez, & Dori, 1998; Naveh-Benjamin, Craik, Perretta, & Tonev, 2000). Table 16.1 shows the results from studies that compared the effects of divided attention at encoding and retrieval. The data are presented as the percentage decline in memory performance due to divided attention during encoding or retrieval, relative to memory performance under full attention conditions. As seen in the table, divided attention at encoding leads to significant declines in memory performance regardless of the type of memory task (i.e., free recall, cued recall, or recognition), the list type (unrelated words or related words), or the age of the subjects. By contrast, divided attention at retrieval usually results in much smaller and sometimes nonsignificant decrements in memory performance, again regardless of the type of memory task, list type, or subject population. There are cases in which significant memory decrements are found due to divided attention at retrieval (Fernandes & Moscovitch, 2000; Park, Smith, Dudley, & Lafronza, 1989); these exceptions will be discussed later in this chapter.

Recent advances in neuroimaging techniques allow one to examine brain activity associated with encoding and retrieval and to investigate the effects of divided attention on encoding-related and retrieval-related brain activity. Shallice, Fletcher, and their colleagues used positron emission tomography (PET) to study the effects of divided attention during encoding (Fletcher et al., 1995; Shallice et al., 1994). Subjects learned a list of paired associates while performing either an easy or a difficult secondary task. Encoding during the easy secondary task was associated with activity in the left inferior prefrontal cortex, a finding that is consistent with much previous work showing activation of this region during episodic encoding, particularly during deep, semantic learning (e.g., Kapur et al., 1994). Moreover, and of particular importance, the difficult secondary task all but obliterated activation of this region in the left prefrontal cortex. These results suggest that memory performance is diminished by a difficult secondary task because it interferes with brain activity mediating semantic encoding processes.

We found these results intriguing and wondered what effect divided attention during retrieval would have on retrieval-related brain activity. Given that memory performance is relatively immune to disruption, we hypothesized that retrieval-related brain activity would also withstand disruption. Our PET studies (N. D. Anderson et al., 2000; Iidaka, Anderson, Kapur, Cabeza, & Craik, 2000) included healthy younger (21–31 years old) and older (63–76 years old) adults who were scanned during encoding or retrieval. We used a cued recall task, in which subjects learned lists of moderately related word pairs (e.g., dentist–glove) and then were given the first word of each pair as a cue to recall the second word. The secondary task was an auditory tone discrimination task. In an "easy" condition, a low tone was presented every 2 seconds and subjects repeatedly pressed a button in response to each tone. In a "difficult" condition, a low and a high tone were presented randomly every 2 seconds and subjects pressed the corresponding button in response to each tone. The auditory-motor demands of these 2 conditions were thus equated, but given the relative automaticity of the easy version of the task, we regarded it as the full attention condition, and given the relative complexity of the difficult version of the task,

TABLE 16.1. Memory costs due to divided attention at encoding or retrieval, expressed as the percentage decline in memory performance from full attention conditions.

Study	#	Memory task	Secondary task	Age	DA at encoding	DA at retrieval
Baddeley 1984	1	FR - UR	Card sorting	Y	35	8
	2	FR - UR	Card sorting	Y	24	14
	2	FR - Rel	Card sorting	Y	22	9
	3	FR - UR	Digit WM	Y	18	7
	4	CR - Rel	Digit WM	Y	24	13
	5	FR - UR	Card sorting	Y	13	3
Park 1989	1	FR - Rel	Odd/Even	Y	38	30
				O	55	15
	2	CR - Rel	Odd/Even	Y	34	19
				O	55	21
Craik 1996	1	FR - UR	Visual RT	Y	43	13
	2	FR - UR	Visual RT	Y	35	11
	3	CR – UR	Visual RT	Y	33	9
	4	Rn – UR	Visual RT	Y	22	1
Anderson 1998	1	FR - UR	Visual RT	Y	28	9
				O	38	10
	2	CR - UR	Visual RT	Y	26	2
				O	49	8
	4	Rn - UR	Visual RT	Y	22	1
				O	18	-1
Naveh-Benjamin 1998	1	CR - UR	Visual RT	Y	35	2
		CR - UR	Visual RT	Y	40	9
		CR - UR	Visual RT	Y	35	2
		CR - UR	Visual RT	Y	43	2
Fernandes 2000	2-3	FR - UR	Word WM	Y	53	37
			Word WM	Y	52	33
	4-5	Rn - UR	Word WM	Y	56	30
			Digit WM	Y	50	13
Naveh-Benjamin 2000[a]	1	CR - UR	Visual Tracking	Y	19	4
	2	CR - UR	Visual Tracking	Y	10	1
	2	CR - UR	Visual Tracking	Y	11	−2
Naveh-Benjamin 2000[b]	1	CR - UR	Visual RT[d]	Y	23	5
		CR - UR	Visual RT[d]	Y	31	6
Naveh-Benjamin 2000[c]	1	CR-UR	Digit WM[e]	Y	60	15
	1	CR-UR	Digit WM[e]	Y	31	4
	2	CR-Med-Intra	Visual RT	Y	16	0
	2	CR-Med-Extra	Visual RT	Y	19	6
	2	CR-Low-Intra	Visual RT	Y	23	2
	2	CR-Low-Extra	Visual RT	Y	19	9

Note. Studies are identified by the first author, year of publication, and experiment number within publication (Naveh-Benjamin 2000[a] = Naveh-Benjamin & Guez, 2000; Naveh-Benjamin 2000[b] = Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000a; Naveh-Benjamin 2000[c] = Naveh-Benjamin, Craik, Perretta, & Tonev, 2000). DA = divided attention, FR = free recall, CR = cued recall, Rn = recognition, UR = unrelated word lists, Rel = related word lists, Intra = Intralist word cues, Extra = Extralist word cues, WM = working memory, RT = reaction time; Y = young, O = old. [d] Results from the 1-press conditions of Naveh-Benjamin, Craik, Gavrilescu, & Anderson (2000) are shown. [e] Results from the second trial of Naveh-Benjamin, Craik, Perretta, & Tonev (2000, Exp. 1) are shown.

we regarded it as the divided attention condition (cf. Fletcher et al., 1995; Shallice et al., 1994). Subjects learned and recalled two lists of word pairs under each of four conditions: *full encoding,* full retrieval; *divided encoding,* full retrieval; full encoding, *full retrieval;* full encoding, *divided retrieval* (the italics denotes the memory phase during which scanning took place).

The behavioral data replicated those in Table 16.1. Specifically, relative to full attention conditions (0.79 words for the younger adults, 0.60 for the older adults), divided attention during encoding led to significant reductions in memory performance (0.58 words for the younger adults, 0.36 for the older adults). By contrast, divided attention during retrieval had much smaller and unreliable effects on memory performance for both age groups (0.75 words for the younger adults, 0.51 for the older adults).

Figure 16.1 (see color plate I) shows the imaging data. We first identified brain regions in which activity was associated with full attention encoding and retrieval in younger and older adults, using an Age × Full Attention Encoding/Full Attention Retrieval design. Panels A and B in Figure 16.1 show regions that were more activated by encoding than retrieval (yellow), and areas that were more activated by retrieval than encoding (blue). For the younger adults (panel A), prefrontal activity during encoding was lateralized to the left hemisphere (the inferior frontal gyrus in particular), whereas prefrontal activity during retrieval was lateralized to the right hemisphere (middle frontal gyrus), consistent with previous findings (Tulving, Kapur, Craik, Moscovitch, & Houle, 1994), although retrieval did include some areas of left prefrontal activity. The older adults revealed a very different pattern (panel B); relative to their younger counterparts (panel A), the older adults had less encoding-related brain activity in the left prefrontal cortex, less retrieval-related brain activity in the right prefrontal cortex, but *more* retrieval-related brain activity in the left prefrontal cortex. This combination of age-related *reductions* in encoding-related and retrieval-related brain activity and age-related *increases* of brain activity in regions not activated by the young is consistent with other reports of dedifferentiation of neurocognitive functioning in older adults (Bäckman et al., 1997; Cabeza et al., 1997; Madden et al., 1999).

Our next analysis identified the effect of divided attention during encoding on brain activity in younger and older adults. The yellow in panels C and D in Figure 16.1, for younger and older adults, respectively, identifies regions that were more active during full than divided attention conditions at encoding, and blue identifies regions that were more active during divided than full attention conditions at encoding. Here we see results that replicate those of Shallice et al. (1994; Fletcher et al., 1995). Specifically, divided attention at encoding reduced encoding-related brain activity in the left prefrontal cortex. The data from the older adults are especially intriguing, because although their left inferior prefrontal cortex was not activated more during encoding than retrieval (panel B), divided attention during encoding nevertheless disrupted activity in this region (panel D). These results indicate that although there are definite age-related differences in encoding-related (and retrieval-related) brain activity, divided attention during encoding affects brain activity similarly in both age groups.

Finally, what about the effects of divided attention on retrieval-related brain activity? Divided attention at retrieval had comparable effects on brain activity in younger and older adults; that is, the interaction of age group and full/divided attention during retrieval on brain activity was not significant. Thus, panel E in Figure 16.1 shows regions that were more activated by full attention retrieval than divided attention retrieval (yellow) and vice versa (blue) for the two age groups combined. This analysis showed that divided attention at retrieval had essentially no effect on retrieval-related brain activity in the prefrontal cortex. Specifically, of the seven prefrontal regions in which activity was reduced by divided attention during retrieval, only one of these, in the left orbital frontal gyrus, was preferentially active during retrieval relative to encoding. These results demonstrate that retrieval-related prefrontal brain activity is relatively immune to disruption by divided attention in both age groups.

In summary, divided attention during encoding reduces memory performance and reduces encoding-related brain activity in the left inferior prefrontal cortex. These results, combined with other research showing that divided attention during encoding reduces levels-of-processing effects (Craik, 1982), increases false alarm rates to semantically related lures (Mandler & Worden, 1973), reduces conscious recollection but not familiarity (e.g., Jacoby, 1991; Jacoby, Woloshyn, & Kelley, 1989), and disrupts conceptual but (usually) not perceptual priming (e.g., Mulligan, 1998), all suggest that divided attention during encoding interferes with deep, semantic processing. By contrast, divided attention at retrieval has small or unreliable effects on memory performance and has essentially no effect on retrieval-related processes mediated by the right prefrontal cortex.

☐ The Attentional Control of Encoding and Retrieval

If encoding and retrieval operate under attentional control, then one should be able to control how much emphasis these processes receive, and memory performance should be affected accordingly. Specifically, in a dual task situation, as one gives more emphasis to encoding or retrieval, memory performance should increase, but secondary task performance should decrease. The results of studies that have compared the attentional control of encoding and retrieval are presented in Table 16.2. These studies have found that memory performance is quite sensitive to modulations in task emphasis when attention is divided during encoding (see also Murdock, 1965) but is less sensitive to modulations in task emphasis when attention is divided during retrieval (N. D. Anderson et al., 1998; Craik et al., 1996). Note that it is not the case that subjects "protect" retrieval, thereby making it insensitive to task emphasis effects, because secondary task performance is affected by task emphasis as much during retrieval as it is during encoding. That is, subjects are complying with the instructions to vary their emphasis between the two tasks, but in the case of divided attention at retrieval, only secondary task performance, and not memory performance is affected. These results indicate that although encoding operates under attentional control, retrieval does not.

TABLE 16.2. Task emphasis effects at encoding or retrieval, expressed as the percentage change between conditions in which the memory task was emphasized and conditions in which the secondary task was emphasized.

					Memory		RT	
Study	#	Memory task	Secondary task	Age	Enc	Ret	Enc	Ret
Craik 1996	2	FR - UR	Visual RT	Y	26	1	14	15
	3	CR - UR	Visual RT	Y	31	3	16	13
	4	Rn - UR	Visual RT	Y	17	3	9	6
Anderson 1998	1	FR - UR	Visual RT	Y	26	14	16	15
				O	29	0	17	8
	2	CR - UR	Visual RT	Y	24	0	18	15
				O	11	0	21	15
	4	Rn - UR	Visual RT	Y	36	3	9	7
				O	12	−2	11	9

Note. Studies are identified by the first author, year of publication, and experiment number within publication. FR = free recall, CR = cued recall, Rn = recognition, UR = unrelated word lists, RT = reaction time, Y = young, O = old.

☐ The Attentional Demands of Encoding and Retrieval

In a divided attention paradigm, disruptions to secondary task performance are taken as an index of the central attentional demands of the memory task (Kahneman, 1973; Kerr, 1973). Table 16.3 shows the results from a number of studies that compared secondary task costs during encoding and retrieval. Both encoding (see also C. M. B. Anderson & Craik, 1974; Griffith, 1976; Johnston, Greenberg, Fisher, & Martin, 1970; Johnston, Griffith, & Wagstaff, 1972; Johnston, Wagstaff, & Griffith, 1972; Martin, 1970; Trumbo & Milone, 1971) and retrieval (see also Griffith, 1976; Johnston et al., 1970; Martin, 1970; Trumbo & Milone, 1971) cause significant disruptions in secondary task performance. These results indicate that both memory processes are quite demanding of attention. However, most studies have found that secondary task costs are greater during retrieval than during encoding, and particular variables such as aging and the type of memory task have different effects on secondary task costs during encoding and retrieval. These results suggest that encoding and retrieval may place different demands on central resources. In particular, as Table 16.3 shows, secondary task costs are larger for older than younger adults, especially during retrieval (N. D. Anderson et al., 1998), and secondary task costs during retrieval are inversely related to the quality of the retrieval cue. Large costs are found during free recall tasks, smaller costs are found during cued recall tasks, and even smaller costs are found during recognition tasks (N. D. Anderson et al., 1998; Craik et al., 1996), and this is particularly true for older adults (N. D. Anderson et al., 1998; Craik & McDowd, 1987).

Two major conclusions can be drawn from these results. First, although retrieval is typically undisrupted by another task and does not operate under attentional control, it is not "automatic" as Baddeley et al. (1984) suggested, because the large secondary task costs indicate that retrieval can be very demanding of attention. Second, the attentional demands of encoding and especially retrieval are greater for older than younger adults, but age-related increases in the attentional demands of retrieval are attenuated by cues that guide retrieval.

☐ The Nature of Episodic Encoding and Retrieval: An Interim Summary

Thus far, the evidence presented indicates that encoding and retrieval differ in terms of their susceptibility to disruption, their attentional control, and their attentional demands. Encoding is prone to disruption by other ongoing tasks and causes significant disruption to a secondary task, both of which suggest that encoding and the secondary task compete for central resources. Encoding is also sensitive to task emphasis instructions, such that subjects remember more when they emphasize learning and remember less when they emphasize the secondary task, indicating that encoding operates under attentional control. By contrast, retrieval is surprisingly immune to disruption by another ongoing task and operates outside of attentional control, although it nevertheless requires central resources. Craik et al. (1996) described retrieval as "obligatory" in the sense that it seems to

TABLE 16.3. Secondary task costs due to divided attention at encoding or retrieval, expressed as the percentage increase relative to full attention conditions.

Study	#	Memory task	Secondary task	Age	DA at encoding	DA at retrieval
Craik 1996	1	FR - UR	Visual RT	Y	10	35
	2	FR - UR	Visual RT	Y	14	29
	3	CR - UR	Visual RT	Y	18	15
	4	Rn - UR	Visual RT	Y	6	8
Anderson 1998	1	FR - UR	Visual RT	Y	19	35
				O	32	101
	2	CR - UR	Visual RT	Y	13	10
				O	31	50
	4	Rn - UR	Visual RT	Y	7	6
				O	15	15
Naveh-Benjamin 2000^{a}	1	CR - UR	Visual Tracking	Y	10	18
	2	CR - UR	Visual Tracking	Y	7	9
	2	CR - UR	Visual Tracking	Y	14	19
Naveh-Benjamin 2000^{b}	1	CR - UR	Visual RT*	Y	4	8
	1	CR - UR	Visual RT*	Y	3	10
Naveh-Benjamin 2000^{c}	2	CR-Med-Intra	Visual RT	Y	1	5
	2	CR-Med-Extra	Visual RT	Y	3	8
	2	CR-Low-Intra	Visual RT	Y	3	1
	2	CR-Low-Extra	Visual RT	Y	2	11

Note. Studies are identified by the first author, year of publication, and experiment number within publication (Naveh-Benjamin 2000^{a} = Naveh-Benjamin & Guez, 2000; Naveh-Benjamin 2000^{b} = Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000; Naveh-Benjamin 2000^{c} = Naveh-Benjamin, Craik, Perretta, & Tonev, 2000). DA = divided attention, FR = free recall, CR = cued recall, Rn = recognition, UR = unrelated word lists, Intra = Intralist word cues, Extra = Extralist word cues, RT = reaction time, Y = young, O = old. * Results from the 1-press condition in Naveh-Benjamin, Craik, Gavrilescu, & Anderson (2000) are shown.

occur regardless of other ongoing activity and task emphasis, while nevertheless consuming attentional resources.

One could argue that if retrieval is obligatory, it should be relatively immune to disruption in all situations. However, some investigators have found rather large decrements in memory performance due to divided attention at retrieval (see Table 16.1). Fernandes and Moscovitch (2000) reported substantial decrements in memory performance due to divided attention at retrieval (up to 37%), and found that the magnitude of these retrieval costs differed across secondary tasks (see also chapter 14 of this volume by Moscovitch, Fernandes, & Troyer). Specifically, word-based secondary tasks such as word recognition and word monitoring resulted in very large decrements to memory performance, while a digit-based monitoring task led to smaller but reliable memory decrements. Park et al. (1989) found that an odd/even digit classification task significantly disrupted free recall and cued recall for both younger and older adults. Both Fernandes and Moscovitch and Park et al. found that divided attention disrupted encoding more than retrieval, but the point here is that the decrements during retrieval were much larger than have been found by N. D. Anderson et al. (1998), Baddeley et al. (1984), Craik et al. (1996). Thus, the question is, Why is retrieval immune to disruption in some experimental paradigms but not others? What sort of theoretical framework can account for these seemingly disparate findings?

☐ A Shared-Time Model of Memory and Concurrent Processing

My thinking about retrieval has been influenced both by the results presented above and by one more result that was first reported by Craik et al. (1996) and was later replicated in my doctoral studies (Anderson, 1998). Craik et al. (1996) presented a "shared-time" model of memory and secondary task reaction time, developed by Richard Govoni. In the model, it was assumed that time is a resource that is shared between the memory task and the secondary task in divided attention conditions. We first derived time-accuracy functions relating encoding or retrieval time to memory performance under full attention conditions. For encoding, and for retrieval in cued recall and recognition, we varied the presentation rate and examined memory performance as a function of the amount of time provided to encode or retrieve. For retrieval in free recall, we plotted cumulative memory performance over a 30-second free recall period. We then investigated the extent to which memory performance under divided attention conditions could be predicted from the combination of the amount of time by which reaction time on the secondary task slowed from single-task to dual-task conditions and the time devoted to the motor demands of the secondary task. This investigation was based on the assumption that secondary task slowing from single- to dual-task conditions reflects the amount of time devoted to the memory task and that subjects can also use the mechanical motor time for memory encoding or retrieval. For example, if a subject's mean reaction time on the secondary task under full attention conditions (i.e., the secondary task performed alone) was 400 ms and under divided attention at retrieval conditions was 600 ms, then we assumed that 200 ms per secondary task response was available for retrieval. If the subject's motor speed (assessed by having subjects repeatedly press a button in response to a predictable pattern of stimuli) was 100 ms per response, then we assumed that this time was also available for retrieval. If the subject made 70 responses to the secondary task during retrieval, then we assumed that she had 21 seconds in total for retrieval (70 responses × (200 ms + 100 ms)). The validity of the shared-time model was then assessed by comparing the recall level under this divided attention condition to the recall level predicted by the time-accuracy functions (e.g., the free recall level corresponding to 21 seconds).

Craik et al. (1996) reported that the shared-time model consistently *overpredicted* memory performance in conditions of divided attention during encoding. That is, subjects recalled fewer words in divided attention at encoding conditions than would be expected, given the amount of time the model predicted they had for encoding. Furthermore, memory performance under conditions of divided attention at encoding fell progressively further from the predicted levels as subjects were instructed to switch their task emphasis from memory encoding to the secondary task. These results showed that divided attention during encoding does more than simply reduce the amount of time available for learning. We suggested that divided attention during encoding may cause subjects to learn words in a less deep or semantic manner, especially when their emphasis is on the secondary task, and we later found tentative support for this hypothesis (Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000). Craik et al. (1996) found a very different pattern of results for conditions of divided attention at retrieval. In this case, memory performance was essentially exactly what would be expected on the basis of the shared-time model, and this was true for divided attention during retrieval in free recall, cued recall, and recognition.

These results were replicated as part of my doctoral studies (N. D. Anderson, 1998), in which attention was divided at encoding or retrieval under each of three task emphasis conditions (emphasize the memory task, emphasize the secondary reaction time task, or emphasize the two tasks equally). I also found that the shared-time model overestimated memory performance in divided attention at encoding conditions but almost perfectly estimated memory performance in divided attention at retrieval conditions. Furthermore, this pattern held for both younger and older adults.

The results from the retrieval conditions in free recall and cued recall are shown in Figure 16.2. The solid curves depict cumulative recall functions for free recall (top panel) and time-accuracy functions for cued recall (bottom panel) for younger and older adults. Although the figure shows the average functions for each age group, it is important to note that the functions were derived for each individual subject. The points on the curves show memory performance in conditions of divided attention at retrieval plotted as a function of the amount of time available for retrieval, as described above. The important finding, shown in Figure 16.2, is that subjects recalled exactly as much as predicted given the amount of time they had to retrieve. In no case did observed memory performance and predicted memory performance differ reliably. Furthermore, the correlations between predicted and observed memory performance ranged from .31 to .72 and were significant in 11 of the 12 conditions (created by the combination of free recall/cued recall × young/old × the three task emphasis conditions).

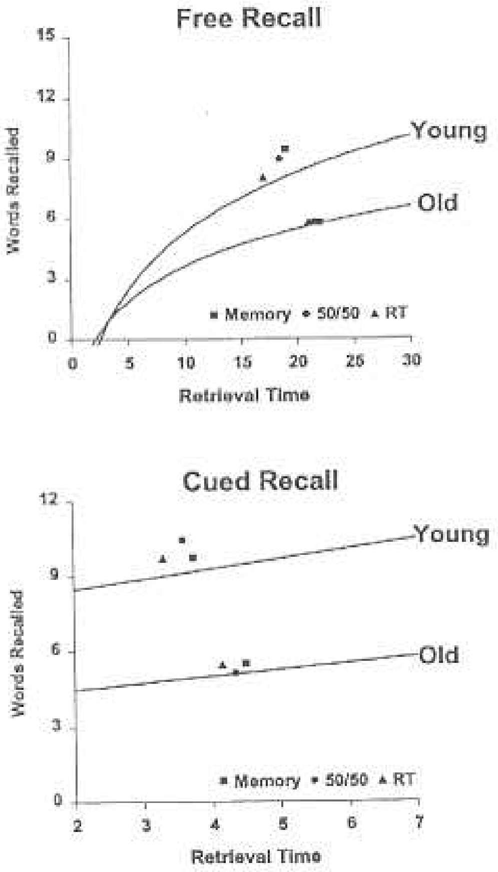


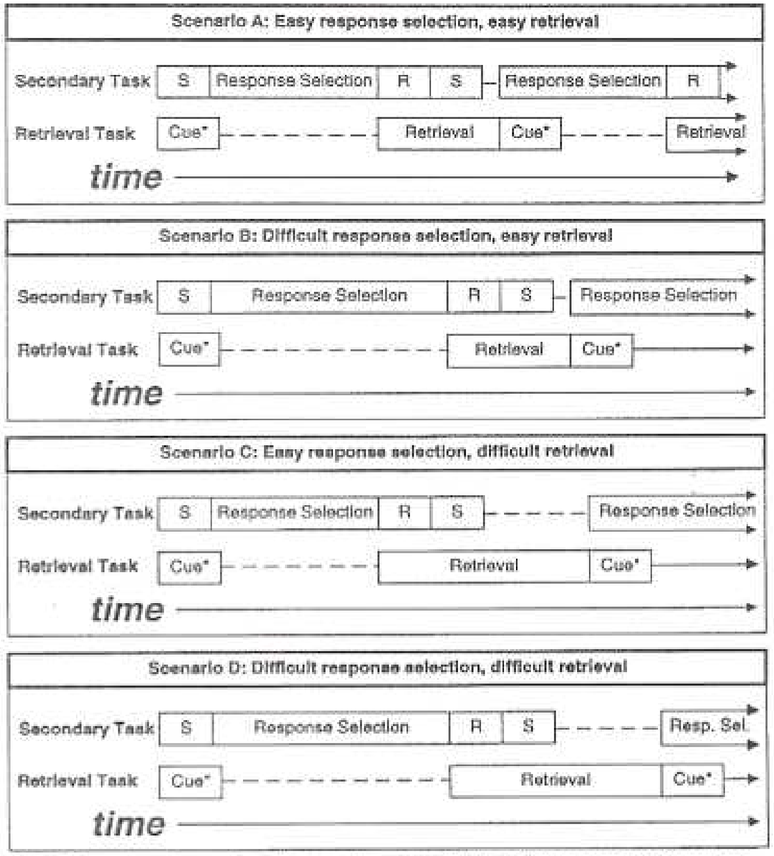
FIGURE 16.2. Solid lines show time-accuracy functions derived from full attention conditions. The data points show memory performance under conditions of divided attention at retrieval in three task emphasis conditions (Mem = memory; RT = reaction time), plotted as a function of the amount of time available for retrieval (see text). From N. D. Anderson (1998).

Craik et al. (1996) concluded from their results that memory retrieval and secondary task performance can operate somewhat in parallel and that the large secondary task costs associated with retrieval reflect the maintenance of retrieval mode (Tulving, 1983) and other strategic retrieval operations perhaps mediated by the frontal lobes. However, a significant problem with the conclusion that retrieval operates in parallel with other ongoing tasks is that it does not account for the fact that retrieval is drastically compromised by divided attention in some situations but not others. What is needed is a theoretical account of retrieval that can explain why it is immune to disruption in many but not all situations, why it operates outside attentional control, why it is highly demanding of attention, and why the shared-time model predicts memory performance under conditions of divided attention at retrieval.

☐ A Bottleneck Model of Retrieval and Concurrent Processing

It is proposed that these disparate findings can be accounted for by applying Pashler's (1994) extension of the psychological refractory period to memory retrieval. Specifically, Carrier and Pashler (1995) found that memory retrieval and response selection on a secondary task could not occur in parallel. The current model proposes that there is a bottleneck encompassing memory retrieval and "central processes" required for response selection on the secondary task. These central processes may include evaluating the significance of the secondary task stimulus (e.g., its position in a four-box array), decision-making processes required for determining a response, and response planning, initiation, and monitoring. For simplicity's sake, I will refer to these operations collectively as response selection, as Pashler (e.g., 1994) does, but the reader should bear in mind that this term encompasses all processes between perception and response production. Neither retrieval nor secondary response selection takes automatic priority over the other, but whichever commences first wins temporary priority, and until it is completed or terminated, the other operation must be suspended. Moreover, although retrieval and secondary task response selection cannot coincide, the relationship between retrieval costs and secondary task costs is not straightforward but is mediated through the participant's retrieval-time-accuracy functions (as shown by Craik et al., 1996). That is, one must know both the amount of time that was available for retrieval and the level of memory performance corresponding to that amount of time. The first component is estimated from the sum of secondary task retrieval costs and motor times, and the second component is estimated from time-accuracy functions.

The model makes a number of predictions, some of which can be assessed vis-à-vis existing data and some of which await future testing. Figure 16.3 diagrams theoretical component operations involved in secondary task performance and memory retrieval and their proposed time-sharing in dual-task conditions. It is assumed that the component operations involved in a secondary task are stimulus identification (denoted as "S" in the figure), "response selection" as described above, and response execution (denoted as "R"



Note: The retrieval cue can be either experimenter provided, as is the case in cued recall and recognition tasks, or subject-generated, as is the case in free recall tasks.

FIGURE 16.3. Theoretical component operations involved in secondary task performance and memory retrieval, and their proposed temporal relationship according to the bottleneck model of memory retrieval and concurrent processing.

in the figure). The component operations involved in memory retrieval are assumed to be cue identification or generation (depending on whether the cue is experimenter provided or subject generated), and retrieval, which in turn is assumed to include ecphory, monitoring, and response output. In the figure, a dashed horizontal line indicates the suspension of operations when a bottleneck between secondary task response selection and memory retrieval occurs.

The primary predictions made by the bottleneck model are as follows:

1. Memory performance in divided attention at retrieval conditions can be predicted from the amount of time remaining after response selection on the secondary task. This is the broadest prediction made by the model, and as described in the preceding section of this chapter, this prediction was upheld by the success of the shared-time model in Craik et al. (1996) and N. D. Anderson (1998).
2. A secondary task involving response selection will slow retrieval relative to full attention retrieval conditions. This prediction can be seen diagrammatically in any of the scenarios shown in Figure 16.3. Indeed, Baddeley et al. (1984) reported that divided attention slowed retrieval, and Carrier and Pashler (1995) and Naveh-Benjamin and Guez (2000) replicated these results. Furthermore, Baddeley et al. (1984) found that retrieval latency increased with increasing secondary task demands, a prediction that would also fall out of the current model.
3. Secondary task costs will increase as retrieval becomes more difficult and more time consuming (see scenarios A and C in Figure 16.3). Specifically, the model predicts that secondary task response selection will be suspended during memory retrieval, and thus more difficult, slower retrieval will result in slower secondary task response times. This prediction has been confirmed by findings of greater secondary task costs during recall than recognition (N. D. Anderson et al., 1998; Craik et al., 1996; Craik & McDowd, 1987), greater secondary task costs during the cued recall of low-frequency than high-frequency words (Naveh-Benjamin et al., 1998; Naveh-Benjamin & Guez, 2000), and greater secondary task costs during recall cued by extralist cues than recall cued by intralist cues (Naveh-Benjamin, Craik, Perretta, & Tonev, 2000b).
4. Memory retrieval costs will increase as secondary task response selection demands increase (see scenarios A and B in Figure 16.3). The model predicts that retrieval will be suspended during secondary task response selection, and thus more time-consuming secondary tasks will lead to greater memory costs. This prediction has not been properly tested. Naveh-Benjamin, Craik, Gavrilesau, and Anderson (2000) compared the effects of a three-choice and a six-choice visual reaction time task on encoding and retrieval in a cued recall task of unrelated word pairs. Relative to the three-choice task, the six-choice task led to longer single-task and dual-task reaction times and caused greater disruptions to memory performance when combined with encoding, but not when combined with retrieval. At first blush, these results are inconsistent with the proposed bottleneck model. However, it must be pointed out that the difference in secondary task costs during retrieval between the two tasks was only 16 milliseconds. Given an estimated average of 12.20 secondary task responses per word retrieved (6,000 ms cue presentation rate divided by the mean reaction time of 492 ms), the amount of time available for retrieval of each word in these two conditions differed by only 195 ms (16 ms × 12.20 responses). Naveh-Benjamin, Craik, Gavrilesau, and Anderson did not collect the data necessary to derive time-accuracy functions, but the functions should be similar to those for retrieval of unrelated word pairs in Figure 16.2 (bottom panel). Inspection of those functions makes it clear that a 195 ms difference between the three- and six-choice task in the time available for retrieval would have little effect on the number of words recalled. According to the model, a more powerful manipulation of secondary task difficulty would be needed to produce differences in retrieval costs.

Fernandes and Moscovitch (2000) proposed a component-process model, which essentially states that verbal secondary tasks activate the same neocortical brain regions as verbal memory traces activated by retrieval, thus producing interference. According to their model, word-based secondary tasks cause particularly substantial interference because of the greater overlap between brain regions activated by the memory task and the secondary task. Their secondary tasks involved monitoring a string for (a) three consecutive odd two-digit numbers, (b) three consecutive two-syllable words, and (c) three consecutive man-made objects. Each of these tasks interfered substantially with retrieval, but the effects were greatest when the secondary task involved words.

Their model is appealing, and it may indeed turn out that memory retrieval costs depend on the overlap among primary and secondary task representations. However, I suggest that the current model offers a more parsimonious explanation, in that the nature of the secondary task is unimportant–what matters is how long the secondary task operations take. Fernandes and Moscovitch did not obtain time-accuracy functions for memory retrieval or measure secondary task latencies. The current model predicts that response selection (i.e., all of the central processes involved in making decisions on the secondary task) on their word-based secondary tasks takes longer than it does on their digit-based secondary tasks (see also Park et al., 1989, who used an odd-even decision secondary task), which in turn takes longer than on visual reaction time tasks. Moreover, the current model predicts that if one used a relatively simple and hence quick word-based secondary task (e.g., press a button if the word "monkey" is presented among a string of words), one would find little cost to memory retrieval.

5. Regardless of a secondary task's response selection demands, memory costs should be larger for free recall than for cued recall or recognition. This prediction has been upheld by N. D. Anderson et al. (1998) and by Craik et al. (1996) and is based on the fact that the slope of time-accuracy functions is generally much greater for free recall than for cued recall or recognition (see Figure 16.2, and Craik et al., 1996). In standard cued recall and recognition paradigms, retrieval runs off quickly, and the provision of additional retrieval time affords little benefit to memory performance. Thus, a reduction in the amount of time available for retrieval due to a secondary task will have little impact on memory performance. Indeed, the results of the shared time model are not shown for the recognition experiment included in N. D. Anderson (1998) because they were flat and near ceiling (~92% hit minus false alarm rate) even at presentation rates of 2 s per item. Of course, at extreme time deadlines (e.g., around 1 s or less), memory performance will be degraded merely because a certain amount of time is needed for cue identification/generation and response output.

   Modified cued recall or recognition procedures (e.g., extralist cuing in which the cue words were not shown during the encoding phase, or same-different recognition discriminations for intact or recombined word pairs) which involve greater generation or monitoring demands should be more susceptible to divided attention at retrieval than their standard counterparts if they lead to steeper time-accuracy functions. This hypothesis has not been properly tested, and at this point, only speculative connections between existing work and the hypothesis can be made. Naveh-Benjamin, Craik, Perretta, and Tonev (2000) found that a visual reaction time task disrupted recall by 0.1 words when cued with intralist cues, and by 0.5 words when cued by extralist cues, a difference that was not significant. Had they analyzed relative costs (1% and 7%, respectively), this difference may have been reliable, but more important to the present point is the fact that time-accuracy functions might be able to shed some light on the reason for the small difference in retrieval costs between these two conditions. For example, it might be that the difference in the amount of time estimated for retrieval in these two conditions (estimated to be only 349 ms: 11.62 responses per word × 30 ms difference in secondary task cost) is not enough if the slopes of the time-accuracy functions are too similar. In a different study, Jacoby (1991) found that divided attention at retrieval impaired recognition of words that had been solved as anagrams but not words that had been read during the learning phase. He furthermore showed that divided attention exerted its effect on recognition judgments based on recollection but not familiarity. According to the current model, these results would be predicted if the slope of the recognition time-accuracy function is much steeper for words originally solved as anagrams than read. If that is the case, then the reduction in the amount of retrieval time due to the secondary task would have much greater consequences for words originally solved as anagrams than read.

6. If memory retrieval and secondary task response selection cannot occur in parallel, performance on a secondary task that allows continuous response measurement should show sharp disruptions during memory retrieval. In the studies conducted by Craik et al. (1996) and N. D. Anderson et al. (1998), the timing of the visual reaction time secondary task relative to the retrieval task operations was not under experimental control. Hence, it was not feasible to measure reaction time as a function of coincident memory operation (e.g., cue identification or generation vs. memory retrieval). In a cued recall paradigm, Naveh-Benjamin & Guez (2000) used a visual-motor tracking task as their secondary task and recorded performance (defined as the distance between the subject-controlled cursor and the target) every 20 ms. They found that secondary task deviations rose sharply during the cue-elaboration/retrieval phase between the presentation of a retrieval cue and the subjects' spoken recall. Carrier and Pashler (1995) used a psychological refractory period design, in which memorized word pairs were tested individually with cued recall or recognition. Memory "strength" was varied by presenting the stimuli for learning once or twice for cued recall, or once or five times for recognition. During the retrieval phase, at experimenter-controlled times prior to the presentation of the retrieval cue (50, 250, or 1250 ms), a high or low tone was played for a two-choice auditory reaction time response. Memory retrieval was slowed when the stimulus-onset-asynchrony (SOA) between the tone and the cue word was shorter, and parallel retrieval latency × SOA functions were obtained for "weak" and "strong" items. That is, retrieval of both strong and weak items was slowed when it was coincident with auditory tone response selection at the shorter SOAs, a finding that provides strong support for a bottleneck between response selection and memory retrieval. Although in this paradigm memory retrieval was the "secondary" task on which processing was slowed by a preceding primary reaction time task, the opposite results should hold if the order of the tasks was reversed. Namely, reaction times to an auditory or visual discrimination task should be slowed until memory retrieval is completed if memory retrieval is initiated first, as shown in Figure 16.3. Both of these methods, a continuous secondary task and an experimenter-choreographed secondary task, allow for more direct observation of the response selection/retrieval bottleneck.

In summary, a bottleneck model, derived from that of Pashler (1994), is proposed in which memory retrieval and secondary task response selection cannot occur in parallel. The strengths of the current model are that it can explain why retrieval is typically (N. D. Anderson et al., 1989; Baddeley et al., 1984; Craik et al., 1996) but not always (Fernandes & Moscovitch, 2000; Jacoby, 1991; Park et al., 1989) immune to disruption by other ongoing tasks, why retrieval causes disruption to secondary task performance, and why retrieval operates outside attentional control. Divided attention sometimes does and sometimes does not lead to significant reductions in memory performance relative to full attention conditions depending on the difficulty of secondary task response selection (e.g., evaluation of the stimulus, decision making, initiation, monitoring, etc.) and on the time-accuracy functions of the memory task. Simply put, more difficult secondary tasks "steal" more time away from memory retrieval, and if the memory task is one in which retrieval is strongly time dependent, large memory costs will be incurred. Retrieval disrupts secondary task performance because it temporarily suspends secondary task response selection. It operates outside attentional control because the bottleneck is not under attentional control. And finally, under conditions of divided attention at retrieval, memory performance is exactly what one would predict given the amount of time remaining for retrieval, because retrieval and secondary task response selection share retrieval time. Time is of greater or lesser importance depending on the nature of the memory task and the individual. It is therefore critical that the relationship between memory retrieval and secondary task performance be interpreted in the context of subject- and task-specific relationships between time and memory performance.

Although bottleneck models of cognitive processing traditionally have been proposed as alternatives to resource models, the fundamental mechanism underlying the current model—time—is a resource that is shared between memory retrieval and response selection on a concurrent task. Retrieval requires time, particularly in more impoverished retrieval environments, and during its operation it forces the suspension of ongoing subsidiary response selection. In a sense, retrieval captures attention, and thus phrases such as "attention demanding" are appropriate descriptions of memory retrieval.

The primary strengths of the proposed model of memory retrieval and concurrent processing are that it accounts for a wide array of seemingly incongruent results and that it generates a number of specific, testable predictions, as outlined above. Nevertheless, what has been described in the current chapter is but an introduction, and thus many important issues have not been addressed. Chief among them is an explanation of why encoding and retrieval differ so drastically in the nature of their vulnerability to disruption, attentional demands, and attentional control. The existing data suggest that encoding is mediated by resources other than or additional to time, but the current model does not specify what those resources may be. The current model, particularly the application of time-accuracy functions as proposed, is also limited because it describes the overall competition between memory retrieval and secondary task response selection for a person and task. It does not take into account the obvious fact that a given person, within a given task, recalls some memoranda quickly and others slowly and may not recall some information at all no matter how much time is provided. Naveh-Benjamin and Guez (2000) found that secondary task tracking costs differed between slow and fast retrievals and between successful and unsuccessful retrievals, with greater and longer sustained costs for slow and unsuccessful retrievals. It is now well established that two processes (recollection and familiarity, or conscious and unconscious, or effortful and automatic) mediate memory retrieval (Atkinson & Juola, 1974; Hasher & Zacks, 1979; Jacoby & Dallas, 1981; Mandler, 1980). Although the current model does not specify how a secondary task differentially affects these processes, it has already been established that a secondary task affects recollection but not familiarity (Jacoby, 1991; Jacoby et al., 1989) and affects explicit and conceptual-implicit but not perceptual-implicit memory (e.g., Mulligan, 1998). Yonelinas and Jacoby (1994) furthermore showed that familiarity is a faster mediator of retrieval than is recollection. The fact that it is recollection and not familiarity that takes time and that is disrupted by divided attention suggests that only the former process shares time as a resource with a secondary task. This suggests that the bottleneck may encompass only recollection and not familiarity, such that familiarity-based retrieval processes (including perceptual-implicit) can operate in parallel with secondary task response selection. That is, the greater, sustained costs associated with slow and unsuccessful retrieval (Naveh-Benjamin & Guez, 2000) may arise when familiarity fails, and recollection plods along in its slow and error-prone way. Finally, what has been described is a cognitive model, not a functional neuroanatomical model. Future research will determine whether retrieval-related activity in the right prefrontal cortex is undisrupted by divided attention because that region mediates both retrieval and response selection, or because it mediates a higher order function such as multitasking, working memory, and monitoring necessary for a wide array of complex cognitive functions (see chapter 10, by Shallice).

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