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The Attentional Demands of Encoding and Retrieval in Younger and Older Adults: 1. Evidence From Divided Attention Costs

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Four studies examined the effects of divided attention in younger and older adults. Attention was divided at encoding or retrieval in free recall (Experiment 1), cued recall (Experiments 2 and 3), and recognition (Experiment 4). Dividing attention at encoding disrupted memory performance equally for the two age groups; by contrast, for both age groups, dividing attention at retrieval had little or no effect on memory performance. Secondary task reaction times (RTs) were slowed to a greater extent for the older adults than for the younger adults, especially at retrieval. Age-related differences in RT costs at retrieval were largest in free recall, smaller in cued recall, and smallest in recognition. These results provide evidence for an age-related increase in the attentional demands of encoding and retrieval.

Despite William James's (1890) confident assertion that "everyone knows what attention is" (p. 403), a precise understanding of attention and its mechanisms still eludes cognitive psychologists. The goal of the current research was to investigate age-related differences in the role of attention in episodic memory encoding and retrieval. We used a divided attention (DA) paradigm, in which a memory task and a secondary task were performed alone for some trials and concurrently for other trials. In a DA paradigm, memory and secondary task performance decrements from single- to dual-task conditions are referred to as "memory costs" and "secondary task costs," respectively.

Attentional Resources Versus Attentional Control

In many theories of attention and of memory, a dichotomy is thought to exist between automatic and controlled processes (e.g., Hasher & Zacks, 1979; Kahneman, 1973; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977), such that controlled but not automatic operations are viewed as being resource demanding. This suggests that attentional control and attentional resources may be synonymous concepts, but recent studies have made it clear that not all resource-demanding cognitive operations are under cognitive control. The evidence from DA studies with younger adults as participants is that, whereas encoding information into episodic memory is both resource demanding and under cognitive control, retrieving information from episodic memory is resource demanding but operates outside cognitive control. Specifically, when attention is divided at encoding, memory performance suffers relative to full attention (FA) conditions (e.g., Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Murdock, 1965). Similarly, secondary task performance is impaired by concurrent encoding processes (e.g., Craik et al., 1996; Griffith, 1976; Johnston, Greenberg, Fisher, & Martin, 1970; Johnston, Griffith, & Wagstaff, 1972; Johnston, Wagstaff, & Griffith, 1972; Martin, 1970; Trumbo & Milone, 1971). Secondary task costs have been interpreted as reflecting the amount of effort, or attentional resources required by the memory task (Kahneman, 1973; Kerr, 1973). Thus, these results suggest that DA disrupts strategic encoding processes and that these encoding processes consume attentional resources. Evidence that encoding operations are under cognitive control is based on the fact that there is a trade-off between memory performance and secondary task performance; that is, when asked to emphasize the memory task, memory performance improves but secondary task performance suffers, and when asked to emphasize the secondary task, memory performance is reduced but secondary task performance benefits (Craik et al., 1996; Murdock, 1965). Taken together, the evidence suggests that memory encoding is resource demanding and under cognitive control.

Further results from DA studies suggest that the retrieval of information from episodic memory is not under cognitive control but that these operations are nevertheless resource demanding. Retrieving information from memory often feels effortful, and thus one would anticipate that retrieval would be

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easily disrupted by a secondary task. Unexpectedly, however, Kellogg, Cocklin, and Bourne (1982); Baddeley et al. (1984); and Craik et al. (1996) found small or no memory disruption when attention was divided at retrieval, in free recall, cued recall, or recognition in younger adults. Furthermore, under conditions of DA during retrieval, memory performance is insensitive to task-emphasis effects (Craik et al., 1996). Baddeley et al. (1984) originally concluded that because retrieval is not affected by DA, retrieval therefore must be automatic, in the traditional sense that processes that cannot be disrupted satisfy one of the criteria for operations that run off without attentional resources (Hasher & Zacks, 1979). However, retrieval from memory does come at a substantial cost to secondary task performance (Griffith, 1976; Johnston et al., 1970; Martin, 1970; Trumbo & Milone, 1971), and Craik et al. (1996) reported that secondary task costs were largest in free recall, moderate in cued recall, and smallest in recognition. In summary, it appears that retrieval is resource demanding but operates without cognitive control, in the sense that there are substantial costs to secondary task performance especially when retrieval must be self-initiated (as in free recall), combined with little or no cost to memory performance, and no effects of task emphasis.

Considered together, the results from the DA literature imply that attentional resources and attentional control are not synonymous concepts but that they can be dissociated. Memory retrieval is one example of a cognitive activity that seems to require attentional resources but to operate outside of attentional control. Other examples of resource-demanding processes operating without cognitive control are available. Yantis and colleagues (e.g., Yantis, 1993; Yantis & Jonides, 1984, 1990) have delineated the various conditions under which the onset of a visual stimulus captures attention. Internal states also can capture attention; for example, action slips can occur when one's attention is focused on their thoughts and away from the task at hand (e.g., Reason, 1979, 1984). It seems clear, however, that the independence of resource demands and cognitive control is not easily accommodated by single-resource theories of attention, and, for other reasons that are outside the scope of this article, the existence of a global pool of processing resources has been hotly debated in the literature (see Hirst & Kalmar, 1987; Navon, 1984, 1985; Navon & Gopher, 1979; Wickens, 1980, 1984).

Two alternative explanatory frameworks are able to accommodate at least some of the DA and memory data described earlier. First, a neuropsychological model provides a new interpretation of DA costs that recasts the resource debate in terms of the functions of different brain regions. According to the "working-with-memory model" put forward by Moscovitch and colleagues (Moscovitch, 1992, 1994; Moscovitch & Umilta, 1990, 1991; Moscovitch & Winocur, 1995), memory involves the interaction of a frontal lobe system that mediates strategic encoding and retrieval processes and a modular medial temporal lobe–hippocampal (MTLH) system that automatically picks up information that has been consciously apprehended. The model also holds that only the strategic frontal system, and not the MTLH, can be disrupted by a secondary task. The results from DA studies are broadly consistent with these ideas. That is, the presence of memory costs under conditions of DA during encoding is consonant with the idea that DA prevents some information from being consciously apprehended (e.g., Moscovitch, 1994). Furthermore, the lack of memory costs and the lack of task emphasis effects under conditions of DA during retrieval are consistent with the notion that when the necessary retrieval cues are provided or are generated internally, controlled frontal operations are bypassed and retrieval is obligatory. When retrieval cues are not provided (e.g., in free-recall tasks), the strategic frontal system is engaged and memory retrieval is impaired by a secondary task, although not to the same extent as happens with DA during encoding (Craik et al., 1996). It is therefore possible to think of attentional resources as increased neural activity (and presumably increased blood flow) in particular brain regions during cognitive tasks and attentional control as a mechanism mediated by the frontal lobes by which the resources are allocated to the various brain regions.

A second explanatory framework that addresses at least some of the DA and memory data is that of a structural bottleneck encompassing memory retrieval and response selection (e.g., Pashler, 1994). Carrier and Pashler (1995) provided evidence that memory retrieval in cued recall and recognition could not occur in parallel with response selection on a secondary task. This account would suggest that secondary task costs arise because performance on the secondary task is delayed until memory retrieval is completed. Furthermore, when retrieval cues are weak or absent, retrieval proceeds more slowly and thus secondary task costs are larger.

The current studies were conceived and planned within the framework of the attentional resource model, and we therefore describe them primarily in these terms. However, these alternative explanatory frameworks (Moscovitch's, 1992, 1994, working-with-memory model and Pashler's, 1994, response bottleneck view) are considered further in the General Discussion section.

DA and Aging

Predictions can be drawn from current theories of cognitive aging about how older adults' performance should be affected by the requirement to divide their attention between a memory task and a secondary task. The reduced attentional resource view (Craik, 1983; Craik & Byrd, 1982; Rabinowitz, Craik, & Ackerman, 1982) suggests that an age-related loss of available resources impairs the ability to engage in demanding operations such as enlisting mnemonic strategies at encoding or generating appropriate cues at retrieval. That is, encoding and retrieval operations are more attention demanding for older adults than for younger adults, and we would therefore predict larger secondary task costs for older than younger adults. Craik (1983, 1986) proposed that supportive encoding and retrieval environments can compensate for the deleterious effects of age-related resource reductions. This hypothesis therefore predicts that age-related elevations in secondary task costs will be reduced when encoding or retrieval cues are provided. Using the process dissociation procedure, Jacoby and colleagues have shown that controlled processes are reduced in advanced age and by DA, whereas automatic processes are spared by both factors (Jacoby, 1991; Jacoby, Woloshyn, & Kelley, 1989; J. M. Jennings & Jacoby, 1993). On the basis of this view, we might expect that older adults would be less able to exercise attentional control of mnemonic operations. Another important question in the literature is whether encoding or retrieval processes play a larger role in age-related memory decrements (see Burke & Light, 1981, for a review). The DA paradigm is well suited to investigate the relative contributions of encoding and retrieval processes to age-related memory decrements; specifically, the DA paradigm can be used to address the extent to which encoding and retrieval are disrupted by a secondary task, if older adults are able to exercise cognitive control of encoding or retrieval, and whether encoding or retrieval is more resource demanding in older adults.

The literature on aging and DA addresses some of these issues but leaves many questions unanswered. First, there is some evidence that DA disrupts encoding processes more for older than younger adults, leading to age-related increases in memory costs. Park, Smith, Dudley, and Lafronza (1989) found larger memory decrements for older than younger adults when attention was divided during encoding of categorized lists and during encoding of word pairs. Similarly, Salthouse, Rogan, and Prill (1984) found an interaction between age group and memory costs when two lists were presented simultaneously compared with the presentation of a single list for serial recall. In other cases in which recall or recognition was the primary task, memory decrements resulting from DA at encoding did not differ between younger and older adults (Baddeley, Logie, Bressi, Della Salla, & Spinnler, 1986; Light & Prull, 1995; Nyberg, Nilsson, Olofsson, & Bäckman, 1997; Park, Puglisi, & Smith, 1986; Park, Puglisi, Smith, & Dudley, 1987). Finally, the two studies that have investigated secondary task costs during episodic encoding both reported larger costs for older than for younger adults; however, both studies are problematic, as Duchek (1984) reported costs only for trials on which retrieval was not successful, and J. R. Jennings, Nebes, and Yovetich (1990) did not find that concurrent processing during encoding impaired memory performance for either age group.

The effects of DA at retrieval in older and younger adults are clearer: For both age groups, memory performance is not affected or is only slightly affected by a secondary task at retrieval (Macht & Buschke, 1983; Nyberg et al., 1997; Park et al., 1989; Whiting & Smith, 1997). By contrast, secondary task performance is more disrupted in older than younger adults, by free recall, cued recall, and recognition (Craik & McDowd, 1987; Macht & Buschke, 1983; Whiting & Smith, 1997). In two studies, age-related differences in secondary task costs were larger during cued recall than during recognition (Craik & McDowd, 1987; Whiting & Smith, 1997), as would be expected according to the environmental support hypothesis, because cued recall requires more self-initiated retrieval activity than does recognition (Craik, 1983, 1986). Taken together, it can be concluded that retrieval is obligatory for both age groups; however, retrieval appears to make greater attentional resource demands on older adults.

Finally, Salthouse et al. (1984) found no age-related differences in the ability to control the allocation of attention between two tasks. In that study, two lists were encoded and retrieved simultaneously, so it is not possible to tease apart cognitive control at encoding and retrieval. The demonstrations by Jacoby and colleagues (Jacoby, 1991; Jacoby et al., 1989; J. M. Jennings & Jacoby, 1993) that controlled memory processes, but not automatic memory processes, are reduced by aging would lead to the prediction that older adults' control over their encoding operations would be impaired.

One must be cautious when interpreting the literature on aging and DA, however, because each study included at least one of the methodological shortcomings discussed by Somberg and Salthouse (1982) and Salthouse, Fristoe, Lineweaver, and Coon (1995). The first limitation of some studies is that attention was divided only at encoding, or only at retrieval, so the separate effects of DA at encoding and retrieval are uncertain. A second limitation is a failure to report single-task performance or the use of a secondary task in which there is no variability in performance; either case precludes analysis of secondary task costs. Finally, secondary tasks such as the detection of occasional targets or card sorting leave indefinite amounts of time to switch focus to the memory task. These limitations were corrected in the current research: A common procedure was used to investigate age-related differences in the effects of DA in free recall, cued recall, and recognition; the separate effects of DA at encoding and retrieval were examined; the secondary task was a continuous reaction time (RT) task; and single-task performance was collected for both tasks.

The Hypotheses

The hypotheses for the current experiments were as follows. First, we hypothesized that DA would disrupt encoding processes in younger and older adults, and thus memory performance should be reduced under conditions of DA during encoding relative to FA conditions. However, given the mixed results in the aging literature, we made no specific predictions regarding age-related differences in memory costs during encoding. Encoding processes are presumed to consume attentional resources, and so RTs during encoding should be slower than they are during FA conditions. Furthermore, if older adults have reduced attentional resources, then encoding operations will be more demanding of attention, and consequently secondary task costs during encoding should be larger for older than for younger adults. Finally, an age-related impairment in controlled memory processes (Jacoby, 1991; Jacoby et al., 1989; J. M. Jennings & Jacoby, 1993) should lead to smaller task-emphasis effects during encoding for older than younger adults. In contrast to encoding, small or no memory costs were expected for either age group during DA conditions at retrieval, and modulations of task emphasis during retrieval should not affect memory performance. Retrieval, although obligatory, demands attentional resources especially when retrieval cues are weak or absent. Thus, we predicted that secondary task RT costs would be greatest in free recall, smaller in cued recall, and smallest in recognition. Finally, if aging is associated with a reduction in attentional resources, then age-related increases in secondary task costs should be largest for free recall, smaller for cued recall, and smaller still for recognition.

General Methods

Similar methods were used in the four experiments described in this article; to simplify the presentation of the experiments, we describe these methods in detail. Specific details and exceptions to these descriptions are noted in the *Method* section for each experiment.

Participants

For Experiments 1, 2, and 4, the data from 24 younger and 24 older adults are presented; for Experiment 3, the data from 24 older adults are presented.[1] No participant was tested in more than one experiment. The younger adults were undergraduate students at the University of Toronto and received course credit for their participation. The older adults were volunteers in an older participant pool maintained in our laboratory and were offered reimbursement of their travel expenses. Specific background information for the younger and the older participants is described separately for each experiment.

Experimental Tasks

Memory task. The stimuli for the memory tasks were common nouns, averaging between 26 and 49 occurrences per million (Kučera & Francis, 1967) depending on the experiment. For the memory task, the words were tape-recorded and presented via a cassette player. The study phase was followed immediately by an arithmetic task to eliminate recency effects. For the arithmetic task, participants heard single digits at a 1.5-s rate and were instructed to add 3 to each digit and to say the sum aloud before the next digit was presented. Twenty digits were presented in 30 s. The arithmetic task was followed immediately by the retrieval phase. In Experiment 1, participants performed the memory task under single-task conditions once, and in Experiments 2–4, participants performed the memory task under single-task conditions twice; the average memory performance of these FA memory trials served as the single-task memory performance for the memory costs described in the *Results* sections.[2]

Note that strategy instructions were provided to all participants. In pilot testing without strategy instructions, the older adults' memory performance was near the measurement floor under conditions of DA at encoding; hence, strategy instructions were provided to elevate performance levels. Also, it seemed likely that the magnitude of secondary task costs would depend partly on the particular strategy adopted by the participant: Some strategies, such as creating a story to connect the words in the list, are probably more resource demanding than are more superficial (and less effective) strategies, such as thinking about the first letter of each word. Thus, we felt that instructing all participants to use the same strategy would facilitate the interpretation of secondary task costs. The specific strategy instructions for each experiment are described in the appropriate *Method* section.

RT task. A four-choice continuous RT task served as the secondary task in these experiments. The RT task involved the visual display of four large boxes on a computer screen. These boxes were outlined in white and were black in the center, displayed against a black background. In one of the boxes selected at random, a center white box appeared, and participants were instructed to press the corresponding button on an external four-button keyboard as quickly and accurately as possible. Participants used two fingers from each hand to perform the task. Most participants used their index and middle fingers, and in all cases it was ensured that participants used the same two fingers on each hand and used the same fingers throughout the duration of the experiment. The accuracy of the response and the RT to the nearest millisecond were recorded by the computer.[3] When a correct buttonpress was recorded, the inner white box disappeared and reappeared immediately in one of the other three boxes chosen randomly.

DA memory task. In each of the four experiments described, six DA memory lists were presented. For three of these lists attention was divided at encoding, and for three of the lists attention was divided at retrieval. When attention was divided at encoding, the RT task began 4–7 s (depending on the experiment) before the list of study words or word pairs began and continued throughout the study phase. Participants were instructed not to stop the RT task during the encoding phase. After the last study word was presented, the RT task ended (the computer screen was cleared), and the arithmetic task began, followed by the retrieval phase, which was conducted under FA. When attention was divided at retrieval, participants first heard the list of words or word pairs to learn under FA, followed by the arithmetic task. When the arithmetic task ended, the four boxes for the RT task appeared on the computer screen and participants started the RT task. Four to 7 s later (depending on the experiment), the retrieval phase began and participants were instructed not to stop the RT task during retrieval. When the

[1] In each experiment, a few participants were excluded for various reasons. In each case, additional participants were tested in their place. In Experiment 1, 1 older adult discontinued participation after the practice trials, 1 older adult was not able to hear the word stimuli presented by the tape recorder, and 1 older adult refused to engage in the RT task during divided attention trials. In Experiment 2, English was not the native language of 1 younger adult, 1 older adult failed to return for his second testing session, and 3 older adults failed to recall more than an average of one word under conditions of full attention (see the *Method* section for Experiment 2). In Experiment 3, 1 older adult's data were quietly discarded after he fell asleep during the testing session.

[2] In Experiments 1, 2, and 4, additional full attention memory lists were presented in which the presentation rates at encoding (and retrieval in Experiments 2 and 4) were varied. In addition, a task designed to assess motor speed was performed in Experiments 1, 2, and 4. The motivation for these manipulations is outside the scope of this article, and the data from these lists are not presented here.

[3] Only correct RTs greater than 100 ms were analyzed. In Experiments 1–3, error rates were 2%–6% across conditions and did not differ between the two age groups. Furthermore, error rates and RTs were positively related; thus, there was no evidence of speed–accuracy trade-offs. In Experiment 4, error rates were 4%–9% across conditions. The younger adults had higher error rates than did the older adults, and the younger, but not the older adults, demonstrated a speed–accuracy trade-off. Therefore, a median split on error rates in the divided attention conditions was conducted within the younger group. The younger adults' mean absolute RT costs were analyzed as a function of error rate group (low vs. high based on the median split), encoding–retrieval, and task emphasis. There was no difference in mean absolute RT costs between the younger adults with high error rates and the younger adults with low error rates. Furthermore, the error rate group did not interact with the encoding–retrieval or with task-emphasis conditions. Thus, the speed–accuracy trade-off in the younger age group did not influence the pattern of their RT costs.

retrieval phase was finished, the boxes disappeared from the screen.

Task emphasis was manipulated within each DA condition. For one list in each DA condition participants were instructed to emphasize the memory task, for a second list participants were instructed to emphasize the RT task, and for a third list they were instructed to emphasize the two tasks equally. These three emphasis conditions were presented in a counterbalanced order within each experiment and are referred to as "memory," "RT," and "50/50," respectively. Participants were instructed that, although they were to emphasize one task over the other in two of those conditions, they were to perform each task as well as possible in the DA conditions.

Response conflict task. A response conflict task was administered to test possible conflicts between verbal responding and the RT task. Craik et al. (1996) found support for McLeod and Posner's (1984) assertion that verbal output in the form of shadowing can be achieved automatically, in that RTs during the response conflict task were no slower than were baseline RTs. These data suggest that making a verbal response in the absence of the need to retrieve the response does not contribute to RT costs. A response conflict task was administered in each of our experiments to assess age-related differences in the automaticity of verbal responding. For the response conflict task, words were presented auditorily via the cassette player, and participants were instructed to repeat each word as they heard it (Experiments 1–3) or respond *yes* or *no* to each word (Experiment 4) while performing the RT task as quickly and accurately as possible.

Procedure

Participants were first given a brief description of the experiment, followed by practice on the arithmetic task alone, the memory task alone, the RT task alone, and then by one trial in which attention was divided at encoding and one trial in which attention was divided at retrieval. Next, participants engaged in the experimental tasks. The Mill Hill Vocabulary Scale (Raven, 1965) and the Wechsler Adult Intelligence Scale–Revised (WAIS-R) Digit Symbol substitution test (Wechsler, 1981) also were administered to each participant; the temporal placement of these tasks relative to the experimental tasks differed across experiments and is described in the *Method* section for each experiment.

Design and Analyses

In each experiment, two versions of the materials were prepared such that the stimulus words were randomly assigned to memory lists separately for each version. In addition, two sets of each version were prepared, so that in each set word lists were assigned to different experimental conditions (i.e., FA at encoding and retrieval, DA at encoding, and DA at retrieval). Six orders of the experimental conditions and six orders of task emphasis also were prepared. The experimental condition orders were created such that memory tasks and RT tasks were alternated; however, the memory lists within an attention condition were performed sequentially (e.g., the three lists in the DA at encoding condition were performed sequentially). A version–set–order combination was randomly assigned without replacement to each participant in each age group.

Absolute and relative DA costs were the dependent measures for the main analyses reported. Absolute memory costs were computed by subtracting dual-task performance from single-task performance, and absolute RT costs were computed by subtracting single-task performance from dual-task performance. Relative memory costs and relative RT costs were computed by dividing the absolute cost by single-task performance. In all cases, a higher value represented a greater DA cost. These costs were submitted to separate 2 × 2 × 3 analyses of variance (ANOVAs), with age group as a between-subjects variable, encoding versus retrieval as a within-subjects variable, and task emphasis (memory, 50/50, and RT) as a within-subjects variable. Further examinations of single-task performance versus dual-task performance (averaged over task-emphasis conditions) were conducted using t tests to determine whether performance was affected by the DA conditions. An alpha level of .05 was used for all t and F tests. Significant interactions were decomposed using Newman–Keuls post hoc tests. Finally, to facilitate comparison across experiments, we report Cohen's d (Cohen, 1969) effect sizes for the age-related differences in memory costs and RT costs at encoding and at retrieval (positive effect sizes indicated larger DA costs for the older than younger adults; negative effect sizes indicated the reverse).

Experiment 1

In Experiment 1 we examined the effects of DA at encoding or retrieval in a free-recall paradigm. Free recall is presumed to place heavy demands on attentional resources; thus, we expected that secondary task costs would be substantial during retrieval, especially for older adults.

Method

Participants. Background information on the 24 younger and 24 older adults is presented in Table 1. The younger and the older adults did not differ in terms of years of formal education or in their current health self-rating ($ts < 1$). The older adults did have higher Mill Hill Vocabulary Scale scores than did the younger adults, $t(46) = 3.70$, p

Table 1
Background Information for Younger and Older Adults Tested in Experiment 1

Variable	Younger *M*	Younger *SD*	Older *M*	Older *SD*
Age	22.5	4.9	68.6	4.5
Education (years)	14.4	1.3	14.9	3.2
Self-reported health	3.3	0.6	3.4	0.8
Mill Hill Vocabulary Scale	19.0	1.9	23.1	5.2
Digit symbol task	70.5	9.1	50.9	9.2

Note. Self-reported health was rated on a scale in which 1 = *poor,* 2 = *fair,* 3 = *good,* and 4 = *excellent.* Mill Hill Vocabulary Scale maximum = 33. Digit symbol scores are the number of correct completions in 90 s.

= .001. The younger adults, however, outperformed the older adults on the WAIS-R Digit Symbol Substitution task, $t(46) = 7.44$, $p < .001$.

Materials and design. The words used in the memory task were 154 two-syllable common nouns, with an average word frequency of 49 occurrences per million (Kučera & Francis, 1967). The stimulus words were randomly allocated to 11 lists of 15 words each separately for the two versions of the materials. In each age group, 12 of the participants were tested on one version and 12 on the other version.

Procedure. The memory task consisted of the presentation of 1 of the 15-word lists at a 5-s rate, followed by the arithmetic task, and then by a 30-s free-recall period, in which participants' responses were tape-recorded for later transcription. Participants were encouraged to create a story to connect the words in the list and to support this mnemonic with visual imagery. Participants performed the memory task once under FA, three times under conditions of DA at encoding, and three times under conditions of DA at retrieval. Participants performed the RT task alone on four occasions, twice for 75 s and twice for 30 s. These task durations were chosen because they matched the durations of the encoding and retrieval phases, respectively. Finally, the response conflict task involved the presentation of a 15-word list at a 5-s rate; participants repeated each word as they heard it and performed the RT task simultaneously.

In summary, the younger and the older participants were first given practice on the memory task alone, then on the RT task alone, and then one trial in which attention was divided during encoding and one trial in which attention was divided during retrieval. Scored trials consisted of (a) the response conflict task; (b) the RT task alone; (c) the memory task alone; (d) three memory trials involving DA at encoding in which the emphasis was on either the memory task, the RT task, or the two tasks equally; and (e) three memory trials involving DA at retrieval in which task emphasis was again manipulated.

The younger participants were tested in one session lasting about 2 hr. The younger participants performed the response conflict task and completed the MHVS and the WAIS-R Digit Symbol Substitution task halfway through the testing session. The older participants were tested in two sessions, each lasting about 1 hr. The first session ended with the response conflict task, and the second session began with the cognitive tests and a 30-s RT warmup trial.

Results and Discussion

Single-task performance. In the memory task under FA conditions, the younger adults recalled more words than did the older adults ($M = 9.75$, $SD = 3.08$ vs. $M = 6.25$, $SD = 2.27$, respectively), $t(46) = 4.48$, $p < .001$. Mean single-task RTs did not differ between the average of the two 30-s trials and the average of the two 75-s trials for the younger adults ($Ms = 417$ and 412 ms, respectively; average $M = 414$ ms, $SD = 59$) or for the older adults ($Ms = 575$ and 573 ms, respectively; average $M = 574$ ms, $SD = 88$). Thus, mean single-task RTs were calculated by averaging over the four RT trials. The younger adults' mean single-task RT was faster than that of the older adults, $t(46) = 7.38$, $p < .001$. RTs during the response conflict task were slower than during the single-task RT task for the older adults ($M = 641$ ms, $SD = 138$), $t(23) = 4.96$, $p < .001$, but not for the younger adults ($M = 410$ ms, $SD = 55$), $t(23) = 1.02$, $p = .32$. The data presented here therefore suggest that a portion of the older adults' larger RT costs (presented later) may be associated with verbal output, which may be less automatic for older than younger adults, although it will be seen that the older adults' RT costs were substantially greater than the 67 ms (641 − 574 ms) attributable to their verbal response generation.

Memory costs. Figure 1A shows the results from the memory task. For both age groups, free-recall levels were disrupted more by DA at encoding than DA at retrieval. In addition, recall levels were more influenced by the emphasis instructions during encoding than during retrieval. As can be seen in Figure 1A, it appears that the younger, but not the older, adults showed an effect of task emphasis at retrieval.

The goal of the first set of analyses was to determine whether encoding or retrieval was impaired by the secondary task. For both age groups, fewer words were recalled when attention was divided at encoding than were recalled in the single-task condition, $t(23) = 5.94$, $p < .001$, for the younger adults, and $t(23) = 6.17$, $p < .001$, for the older adults. DA during retrieval resulted in a small but reliable decrement in memory performance relative to the single-task condition for the younger adults, $t(23) = 2.17$, $p = .04$, but not for the older adults, $t(23) = 1.35$, $p = .19$. Thus, DA during encoding impaired memory performance for both age groups, but DA during retrieval resulted in either a small (but reliable) or no reduction in memory performance.

The goal of the second set of analyses was to examine memory costs as a function of age group, encoding–retrieval, and task emphasis instructions. Absolute and relative memory costs were examined in separate ANOVAs and are described in turn. Absolute memory costs did not differ significantly between the two age groups ($F < 1$, $MSE = 19.71$); absolute memory costs were numerically (but not reliably) larger for the younger adults and so the corresponding effect sizes for the age-related differences in memory costs were relatively small: −.16 at encoding and −.23 at retrieval. Absolute memory costs were larger at encoding than at retrieval, $F(1, 46) = 48.51$, $p < .001$, $MSE = 4.69$, similarly for the older and the younger adults ($F < 1$, $MSE = 4.69$). Absolute memory costs were affected by the task-emphasis instructions, $F(2, 92) = 8.08$, $p = .001$, $MSE = 4.20$; however, the task-emphasis effect was comparable for the two age groups, $F(2, 92) = 1.59$, $p > .10$, $MSE = 4.20$, and was no greater at encoding than at retrieval, $F(2, 92) = 1.43$, $p > .10$, $MSE = 4.16$, and the three-way interaction (Age Group × Encoding and Retrieval × Task Emphasis) was not significant ($F < 1$, $MSE = 4.16$).

The analysis of relative memory costs was almost perfectly consistent with the analysis of absolute memory costs. That is, DA during encoding resulted in worse memory performance than in the single-task condition for both age groups, $t(23) = 4.61$, $p < .001$, for the younger adults and $t(23) = 7.29$, $p < .001$, for the older adults. Whereas the analysis of absolute memory costs revealed a small but reliable effect of DA during retrieval on younger but not older adults' memory performance (relative to the single-task condition), relative memory costs at retrieval did not differ reliably from zero for either age group, $t(23) = 1.28$, $p > .10$, for the younger adults and $t(23) = 0.58$, $p > .10$, for the older adults. Relative memory costs did not differ between the two age groups ($F < 1$, $MSE = 0.29$), but they were larger during encoding than during retrieval, $F(1, 46) = 36.61$, $p < .001$, $MSE = 0.12$, and varied with task emphasis, $F(2, 92) = 4.64$, $p < .05$. None of the remaining effects on relative memory costs was significant.

In summary, DA during encoding impaired memory performance equally for the two age groups, whereas DA during re-

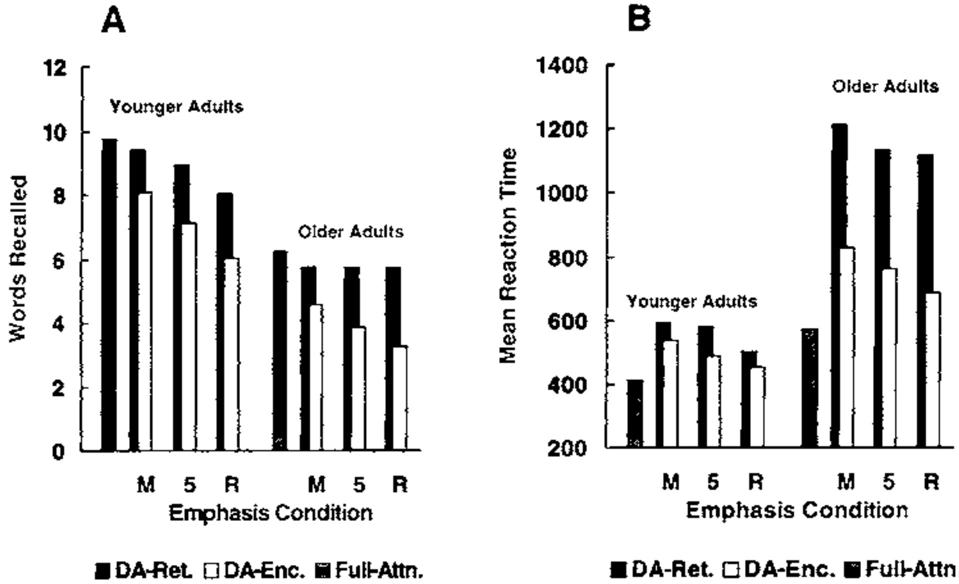

Figure 1. A: Number of words recalled (free recall) under conditions of full attention (Full-Attn.), divided attention at encoding (DA-Enc.), and divided attention at retrieval (DA-Ret.). Instructions emphasized the memory task (M), the reaction time task (R), or the two tasks equally (5). B: Performance on the reaction time task under full and divided attention conditions (Experiment 1).

trieval led to small or nonsignificant effects on memory performance. On the basis of previous research (Craik et al., 1996), we expected that the task-emphasis instructions would affect memory performance only in DA during encoding conditions, not during DA during retrieval conditions. Memory performance was sensitive to task-emphasis instructions, and there did appear to be a *numerical* asymmetry between the effects of task-emphasis instructions during encoding and retrieval, at least for the older adults; however, neither the interaction between encoding–retrieval and task emphasis nor the three-way interaction among age group, encoding–retrieval, and task emphasis was significant. Note that the power to detect these interactions was fairly low (ranging from .08 to .34); thus, had more participants been tested, or had the measures been less variable, these effects may have been significant. Alternatively, it might be the case that recalling a story is one retrieval strategy that is under attentional control; in the experiment reported by Craik et al., strategy instructions were not provided, and so few participants may have spontaneously used this strategy. Nevertheless, the conclusion that encoding, but not retrieval, is under attentional control was not fully supported by these data.

RT costs. The mean RT data are presented in Figure 1B. For both age groups, mean RTs were elevated in the DA conditions relative to single-task RT performance. Retrieval was associated with greater RT costs than was encoding, and task-emphasis instructions influenced RTs during both encoding and retrieval. Most notable in Figure 1B is that the older adults were more slowed by DA conditions than were the younger adults, especially during retrieval.

For both age groups, secondary task RTs were slowed by encoding relative to single-task RTs, $t(23) = 4.36$, $p < .001$, for the younger adults, and $t(23) = 8.50$, $p < .001$, for the older adults. Retrieval similarly slowed RTs for the younger adults, $t(23) = 6.89$, $p < .001$, and for the older adults, $t(23) = 7.72$, $p < .001$. Thus, both phases of the memory task made significant demands on attentional resources for both age groups. The ANOVA on absolute RT costs showed that the older adults had larger RT costs than did the younger adults, $F(1, 46) = 34.69$, $p < .001$, $MSE = 154.66$, and that RT costs were greater at retrieval than at encoding, $F(1, 46) = 40.96$, $p < .001$, $MSE = 94.10$. The age-related increase in absolute RT costs was larger during retrieval than during encoding, $F(1, 46) = 20.78$, $p < .001$, $MSE = 94.10$, with corresponding age-related effect sizes of 0.97 and 1.26 for encoding and retrieval, respectively. Finally, RTs were affected by the task-emphasis instructions, $F(2, 96) = 9.72$, $p < .001$, $MSE = 26.46$, but the task-emphasis effect did not vary with age group or encoding–retrieval (no other interactions were significant, $Fs < 1$).

The analysis of relative RT costs revealed parallel results. That is, relative RT costs were reliably greater than zero for both age groups during encoding, $t(23) = 5.12$, $p < .001$, for the younger adults, and $t(23) = 8.06$, $p < .001$, for the older adults, as well as during retrieval, $t(23) = 7.27$, $p < .001$, for the younger adults, and $t(23) = 9.57$, $p < .001$, for the older adults. Relative RT costs were larger for the older adults than for the younger adults, $F(1, 46) = 32.09$, $p < .001$, $MSE = 0.36$, and were larger during retrieval than during encoding, $F(1, 46) = 59.77$, especially for the older adults, $F(1, 46) = 20.96$, $p < .001$, $MSEs = 0.20$. Finally, relative RT costs were sensitive to task-emphasis instructions, $F(2, 92) = 16.35$, $p < .001$, $MSE = 0.08$, but no other effects were significant ($Fs < 1$). These data provide strong support for the conclusion that both encoding, and especially retrieval, are more demanding of attention in older than younger adults.

Experiment 2

The environmental support hypothesis (Craik, 1983, 1986) predicts that the provision of retrieval cues should lessen the need for self-initiated, resource-demanding operations. In Experiment 2, a cued-recall paradigm was used. The main prediction was that age-related differences in secondary task costs during retrieval would be reduced relative to those found in the free-recall experiment.

Method

Participants. Background information on the 24 younger and 24 older adults is presented in Table 2. The older adults had more years of formal education than did the younger adults, $t(46) = 2.10$, $p = .04$, and higher Mill Hill Vocabulary Scale scores, $t(46) = 8.98$, $p < .001$. The younger adults, however, outperformed their older counterparts on the WAIS-R Digit Symbol Substitution test, $t(46) = 6.00$, $p < .001$. Self-reported health ratings did not differ between the two age groups, $t(46) = 1.85$, $p = .07$.

Materials and design. The stimulus words were 276 two- and three-syllable common nouns, with an average word frequency of 41 occurrences per million (Kučera & Francis, 1967). The nouns were paired randomly with the restriction that there would be no obvious association between the two words in a pair. Word pairs were randomly assigned to 11 lists of 12 word pairs each, separately for the two versions of the materials. The remaining 12 single words were assigned to the response conflict task.

Procedure. For the memory tasks, 12 word pairs were presented at a 7-s rate. Participants were instructed to create a visual image or verbal mediator to connect the two words in each pair. The encoding phase was followed immediately by the arithmetic task and then by the recall phase. In the recall phase, participants heard the first word of each word pair at a 7-s rate in an order random with respect to the order in which the word pairs were presented at encoding. Participants were instructed to recall verbally the second word of each pair. The practice phase consisted of the arithmetic task, one memory list alone, the RT task alone, one trial in which attention was divided at encoding, and one trial in which attention was divided at retrieval. For the scored trials, the memory task was performed twice under FA conditions, on three occasions under DA at encoding conditions (memory, 50/50, and RT emphasis), and on three occasions under DA at retrieval conditions (memory, 50/50, and RT emphasis). Participants also performed the RT task alone twice for 84 s and the response conflict task for 84 s.

The younger adults were tested in one session lasting about 2 hr. The younger adults completed the response conflict task, the Mill Hill Vocabulary Scale, and the WAIS-R Digit Symbol Substitution task halfway through the testing session. The older adults were tested in two sessions. For the first 12 older participants tested, the second session started with the response conflict task and then the Mill Hill Vocabulary Scale and Digit Symbol tasks. However, we felt that RTs on the response conflict task might be slower at the beginning of Session 2 because participants had not practiced the RT task in at least a day. Thus, the remaining older participants performed the response conflict task at the end of Session 1, and began Session 2 with the vocabulary and Digit Symbol tests as well as a 30-s RT warmup trial.

Results and Discussion

Single-task performance. The younger adults recalled more words ($M = 10.25$, $SD = 1.45$) under FA conditions than did the older adults ($M = 5.88$, $SD = 2.50$), $t(46) = 7.42$, $p < .001$. The younger adults' average single-task RT ($M = 409$ ms, $SD = 55$) was faster than that of the older adults ($M = 516$ ms, $SD = 74$), $t(46) = 5.67$, $p < .001$. The younger adults' response conflict RTs ($M = 395$ ms, $SD = 50$) were reliably faster than their single-task RTs, $t(23) = 8.05$, $p < .001$. For the older adults, response conflict RTs were slower than single-task RTs only for the 12 participants who began the second testing session with the response conflict task and so had not practiced the RT task in at least a day (response conflict $M = 562$ ms, $SD = 75$), $t(11) = 7.96$, $p < .001$; by contrast, the response conflict RTs of the 12 older participants who performed the task at the end of the first testing session were not significantly greater than their single-task RTs (response conflict $M = 546$ ms, $SD = 93$), $t(11) = 0.96$, $p = .36$. Taken together with the results from the first experiment, we do not yet know whether some of the older adults' elevated RT costs during retrieval represented age-related increases in the attentional demands of verbal response production. We readdress this issue in the General Discussion section.

Memory costs. Figure 2A shows the results from the memory task. As in Experiment 1, DA at retrieval had little effect on memory performance relative to FA conditions. DA at encoding, on the other hand, was associated with larger reductions in memory performance. The only difference apparent between the younger and the older adults was that the younger adults showed

Table 2
Background Information for Younger and Older Adults Tested in Experiments 2 and 3

	Experiment 2				Experiment 3	
	Younger		Older		Older	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	21.0	3.2	67.9	3.9	69.2	4.7
Education	14.6	2.1	16.3	3.4	15.7	3.1
Self-reported health	3.3	0.5	3.6	0.5	3.6	0.6
Mill Hill Vocabulary Scale	18.3	2.5	25.8	3.3	26.2	4.2
Digit symbol task	67.9	9.6	51.8	9.3	53.0	11.8

Note. Self-reported health was rated on a scale in which 1 = *poor*, 2 = *fair*, 3 = *good*, and 4 = *excellent*. Mill Hill Vocabulary Scale maximum = 33. Digit symbol scores are the number of correct completions in 90 s.

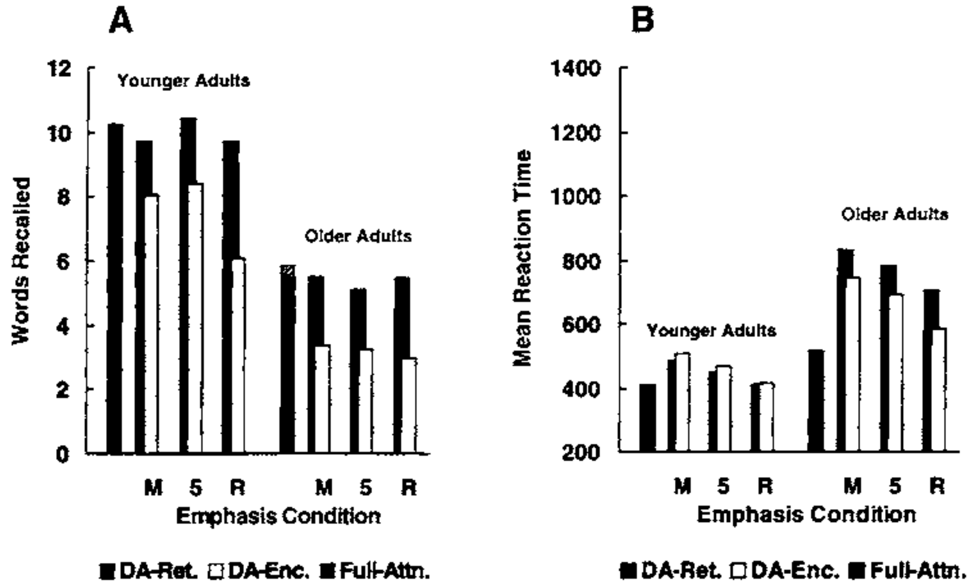

Figure 2. A: Number of words recalled (cued recall) under conditions of full attention (Full Attn.), divided attention at encoding (DA-Enc.), and divided attention at retrieval (DA-Ret.). Instructions emphasized the memory task (M), the reaction time task (R) task, or the two tasks equally (5). B: Performance on the RT task under full and divided attention conditions (Experiment 2).

a larger effect of task-emphasis instructions during encoding than did the older adults.

Compared with FA memory performance, DA during encoding impaired memory performance for both age groups, $t(23) = 6.32$, $p < .001$, for the younger adults, and $t(23) = 6.84$, $p < .001$, for the older adults. By contrast, memory performance was not disrupted reliably by the secondary task during retrieval for the younger adults, $t(23) = 1.29$, $p = .21$, or for the older adults, $t(23) = 1.43$, $p = .17$. The 2 × 2 × 3 ANOVA showed that absolute memory costs did not differ between the two age groups ($F < 1$, $MSE = 15.55$) but that they were larger at encoding than at retrieval, $F(1, 46) = 114.69$, $p < .001$, $MSE = 3.28$, similarly for the younger and the older adults ($F < 1$, $MSE = 3.28$). The corresponding effect sizes for the age-related differences in memory costs were −.03 at encoding and .14 at retrieval. There was a main effect of task emphasis, $F(2, 92) = 6.28$, $p = .003$, $MSE = 2.37$, but this effect should be considered in light of the Age Group × Task Emphasis interaction, $F(2, 92) = 6.18$, $p = .03$, $MSE = 2.37$, and the Encoding–Retrieval × Task Emphasis interaction, $F(2, 92) = 4.39$, $p = .02$, $MSE = 2.35$. Post hoc tests on these interactions showed that only the younger adults' memory performance was affected by task-emphasis instructions and that memory performance was affected by task-emphasis instructions only during encoding. On the basis of this pattern of two-way interactions, one would expect a significant three-way interaction among age group, encoding–retrieval, and task emphasis: The three-way interaction was not significant, $F(2, 92) = 1.81$, $p < .17$, $MSE = 2.35$, but note that the power to detect this interaction was not large ($1 - \beta = .37$).

The relative memory costs revealed similar results. First, the relative memory costs were reliably greater than zero during encoding for both age groups, $t(23) = 5.86$, $p < .001$, for the younger adults, and $t(23) = 6.70$, $p < .001$, for the older adults, but not during retrieval, $t(23) = 0.81$, $p = .43$, for the younger adults, and $t(23) = 0.25$, $p = .80$, for the older adults. The relative memory costs did not differ between the two age groups, $F(1, 46) = 1.40$, $p = .24$, $MSE = 0.38$, but they were larger during encoding than during retrieval, $F(1, 46) = 92.90$, $p < .001$, $MSE = 0.09$. In contrast to the analysis of absolute memory costs, there was a significant Age Group × Encoding–Retrieval interaction for the relative memory costs, $F(1, 46) = 6.48$, $p < .01$, $MSE = 0.09$. Post hoc tests on this interaction revealed that relative memory costs did not differ between the two age groups during retrieval but that they were larger for the older adults during encoding. Also in contrast to the analysis of absolute costs, the task-emphasis instructions did not result in a reliable main effect on the relative memory costs, $F(2, 92) = 1.38$, $p = .26$, $MSE = 0.09$. However, post hoc tests on the reliable Encoding–Retrieval × Task Emphasis interaction, $F(2, 92) = 3.57$, $MSE = 0.06$, revealed that relative memory costs were sensitive to task-emphasis instructions during encoding but not during retrieval. Finally, post hoc tests on the marginally significant interaction between age group and task emphasis, $F(2, 92) = 2.93$, $p = .06$, $MSE = 0.09$, showed that relative memory costs were (marginally) more sensitive to task-emphasis instructions among the younger than the older adults. As in the analysis of absolute memory costs, on the basis of this pattern of two-way interactions, one would expect the three-way interaction among age group, encoding–retrieval, and task emphasis to be reliable, but again, it was not ($F < 1$, $MSE = 0.06$), probably because of the limited power to detect this interaction ($1 - \beta = .17$).

Taken together, these results confirm those from the first experiment and those of Craik et al. (1996) in showing that memory performance was more impaired by DA during encoding than by DA during retrieval. Absolute memory costs were equivalent for the younger and older adults; age-related differences in relative memory costs, on the other hand, were larger for the older adults during encoding but not during retrieval. Compared with the free-recall experiment, neither age group showed robust attentional control of encoding. One explanation for these findings is that the encoding strategies that participants were instructed to use in this study (i.e., to use visual imagery, verbal mediators, or both to connect the two words in each pair) might have been less amenable to alterations in the allocation of attention between encoding and the secondary task. Note, too, that in this experiment there was some evidence for an age-related reduction in the sensitivity of memory performance to the task-emphasis instructions, whereas the free-recall study revealed no such age-related decline. Given these mixed results, we had to await the results of the next two studies before drawing conclusions about age-related changes in the attentional control of encoding and retrieval.

RT costs. Figure 2B shows the mean RT data. For both age groups, dual-task RTs were slower than single-task RTs. For the younger adults, there did not appear to be a difference between dual-task RTs at encoding and retrieval; for the older adults, on the other hand, RTs during retrieval were slower than they were during encoding.

RTs were slowed relative to FA conditions, both during encoding, $t(23) = 5.15$, $p < .001$, for the younger adults and $t(23) = 6.32$, $p < .001$, for the older adults, as well as during retrieval, $t(23) = 3.61$, $p = .001$, for the younger adults and $t(23) = 8.92$, $p < .001$, for the older adults. Absolute RT costs were larger for the older adults than for the younger adults, $F(1, 46) = 43.98$, $p < .001$, $MSE = 42.29$. The main effect of encoding–retrieval, $F(1, 46) = 6.66$, $p = .01$, $MSE = 19.82$, suggested that absolute RT costs were greater at retrieval than they were at encoding; however, this effect was involved in an Age Group × Encoding–Retrieval interaction, $F(1, 46) = 11.17$, $p = .002$, $MSE = 19.82$. That is, the age-related differences in RT costs were larger at retrieval than at encoding; the corresponding age-related effect sizes were 0.97 at encoding and 1.41 at retrieval. Note that although the age-related difference in RT costs during retrieval was larger during free recall (Experiment 1) than during cued recall (Experiment 2), the age-related RT cost effect size was actually smaller during free recall because the RT data were considerably more variable in that case. Additional post hoc tests conducted on the Age Group × Encoding–Retrieval interaction showed that for the younger adults, RT costs were equivalent at encoding and retrieval but that for the older adults RT costs were reliably higher at retrieval than at encoding. Finally, RTs were influenced by task-emphasis instructions, $F(2, 92) = 47.21$, $p < .001$, $MSE = 6.32$, and the older adults' RTs were more influenced by emphasis instructions than were the RTs of the younger adults, $F(2, 92) = 3.82$, $p = .03$, $MSE = 6.32$. Task-emphasis instructions affected RTs at encoding and retrieval equally, and the Age Group × Encoding–Retrieval × Task Emphasis interaction was not reliable ($Fs < 1$, $p > .39$, $MSE = 5.86$).

The analysis of relative RT costs was largely consistent with the analysis of the absolute RT costs. That is, relative RT costs were reliably larger than zero for both age groups during encoding, $t(23) = 5.42$, $p < .001$, for the younger adults, and $t(23) = 6.62$, $p < .001$, for the older adults, and during retrieval, $t(23) = 3.89$, $p = .001$, for the younger adults, and $t(23) = 10.13$, $p < .001$, for the older adults. Relative RT costs were larger for the older adults than for the younger adults, $F(1, 46) = 43.87$, $p < .001$, $MSE = 0.13$, and were larger during retrieval than during encoding, $F(1, 46) = 5.72$, $p = .02$, $MSE = 0.07$, particularly for the older adults, $F(1, 46) = 12.36$, $p = .001$, $MSE = 0.07$. Relative RT costs were affected by task-emphasis instructions, $F(2, 92) = 54.29$, $p < .001$, $MSE = 0.02$; however, in contrast to the analysis of absolute RT costs, the effect of task-emphasis instructions did not differ as a function of age group, $F(2, 92) = 2.25$, $p = .11$, $MSE = .02$. Task-emphasis instructions had comparable effects on relative RT costs during encoding and during retrieval for both age groups (Task Emphasis × Encoding–Retrieval and the three-way interaction, $Fs < 1$, $MSE = 0.02$).

We think that a comparison of the results from the first two studies is instructive, although readers should remember that there were several procedural differences between the two studies (e.g., list length, presentation rate, encoding instructions, word vs. word pair stimuli). As predicted, the difference between secondary task RTs during encoding and retrieval was smaller when a cued-recall task was used than when a free-recall task was used, especially for the older adults. These results are consistent with the environmental support hypothesis that the provision of a retrieval cue compensates for age-related reductions in processing resources that are needed to fuel complex cognitive operations such as retrieval. According to the environmental support hypothesis, the age-related differences in FA memory performance also should have been reduced relative to free recall. Although the age-related decrement in FA memory performance was not reduced by cued recall, the proportion of words recalled under FA conditions was larger for cued recall than for free recall both for the younger and for the older adults (note that the list length was 15 words for free recall and 12 pairs for cued recall).

Results of the first two experiments showed that there were no age-related differences in absolute memory costs at encoding and retrieval but that both processes (especially retrieval) were more demanding of attention in older adults. Although these conclusions seem reasonable, the possibility remains that floor effects contributed to the findings that memory costs were equivalent in the two age groups and that the older adults' memory performance was less affected by the task-emphasis instructions in Experiment 2. We thought that floor effects had not influenced the results obtained. First, the standard deviation of the older adults' memory performance under DA at encoding conditions ranged from 2.0 to 2.2 words in Experiment 1 and from 2.0 to 2.4 words in Experiment 2. Second, on only two occasions in Experiment 1 and seven occasions in Experiment 2 (out of 72 in each Experiment—24 participants × 3 trials in which attention was divided at encoding) did the older adults fail to recall any words from the list.

Nevertheless, we conducted an additional experiment in which only older adults were tested and moderately related word pairs were used. The goal of this study was to match FA memory performance of the older adults who received these moderately related word pairs to the FA memory performance of the younger adults in Experiment 2 who received the unrelated word pairs. If the same pattern of memory costs were to hold for the older adults regardless of baseline memory performance levels, then we could be certain that measurement restrictions were not responsible either for the finding of comparable memory costs in younger and older adults or for the smaller task-emphasis effect on the older adults' memory performance in cued recall.

Matching the baseline memory performance of younger and older adults addresses another issue persistent in the literature: whether absolute costs (FA − DA for memory performance) or relative costs [(FA − DA)/FA] should be examined. Whenever differences in baseline performance between two groups exist, differences between absolute and relative costs are probable. In the first two experiments, the absolute costs and the relative costs led to fairly comparable results; however, there were some discrepancies between these two analyses. A discussion of the theoretical debates surrounding the use of absolute and relative costs is outside the scope of this article, but interested readers should refer to Guttentag (1989) and Somberg and Salthouse (1982). For this series of experiments, we decided not to attempt to match the baseline memory performance of the younger and older adults within a study; to do so would have required substantially different procedures for the two age groups and would have left open the possibility that such procedural differences would affect the processes required by the tasks. The goal of Experiment 3 was to slightly alter the procedure of Experiment 2, which would elevate the older adults' FA memory performance to the level of the younger adults in Experiment 2. We decided to use moderately related word pairs to facilitate the mnemonic strategy of finding a connection between the words in the pairs. If the magnitude of absolute memory costs under these conditions does not differ from those seen in the older adults learning unrelated word pairs, then it can be concluded that regardless of baseline memory performance, there are no age-related differences in absolute memory costs.

Experiment 3

In Experiment 3, older adults were presented with conceptually related word pairs for a cued-recall test. The goal of this experiment was to examine whether the magnitude of absolute memory costs would depend on the level of FA memory performance.

Method

Participants. Background information on the participants is shown in the right-hand column of Table 2. This sample of older adults did not differ from the older adults tested in Experiment 2 in terms of age, years of formal education, self-rated health status, MHVS scores, or Digit Symbol Substitution scores (for each comparison, $t < 1$).

Materials and design. The words used in the memory task were 276 common two- and three-syllable nouns, with an average word frequency of 26 occurrences per million (Kučera & Francis, 1967). The words were paired such that there was a moderate, conceptual relationship between the words. Two examples of word pairs used in this experiment are "lover–balcony" and "camera–tourist." Two versions of the materials were constructed such that the word pairs were randomly assigned to 11 lists of 12 word pairs separately for each version. The remaining 12 single words were assigned to the response conflict task.

Procedure. The tasks and task durations used in this experiment were identical to those described in Experiment 2 (except see Footnote 2). Participants were tested in one session lasting about 1 hr, 15 min. Participants were administered the response conflict task, the Mill Hill Vocabulary Scale, and the WAIS-R Digit Symbol Substitution test halfway through the testing session.

Results and Discussion

Single-task performance. Participants recalled an average of 9.04 words ($SD = 2.57$) under FA conditions; although this level of FA memory performance was marginally worse than the younger adults' FA memory performance in Experiment 2 ($M = 10.25$, $SD = 1.45$), $t(46) = 2.00$, $p = .05$, it was clear that floor effects were avoided. The average mean RT under FA conditions was 549 ms ($SD = 86$) and did not differ significantly from that of the older adults in Experiment 2 ($M = 516$, $SD = 74$), $t(46) = 1.41$, $p = .16$. Participants' RTs on the response conflict task ($M = 558$, $SD = 90$) did not differ reliably from their single-task RTs, $t(23) = 1.47$, $p = .15$.

Memory costs. Figure 3A shows the memory performance of the 24 older participants in this study. Memory performance was disrupted by the secondary task at encoding, but not at retrieval, $ts(23) = 6.33$ and 1.35, $ps < .001$ and $= .19$, respectively. Absolute memory costs were compared with those of the older adults in Experiment 2 using a 2 × 2 × 3 ANOVA design, with experiment (Experiment 2 with unrelated word pairs vs. Experiment 3 with moderately related word pairs) as a between-subjects variable and encoding–retrieval and task-emphasis instructions as within-subjects variables. The magnitude of absolute memory costs did not differ between the moderately related and the unrelated word pairs ($F < 1$, $MSE = 16.38$). Memory costs were greater at encoding than at retrieval, $F(1, 46) = 97.70$, $p < .001$, $MSE = 2.93$. No other main effects or interactions with absolute memory costs as the dependent measure were significant ($Fs < 1.05$, $ps > .35$).

The analysis of relative memory costs largely concurred with these results. Specifically, relative memory costs differed reliably from zero during encoding, $t(23) = 5.53$, $p < .001$, but not during retrieval, $t(23) = 0.33$, $p = .75$. Relative memory costs did not differ between the moderately related and the unrelated word pairs, $F(1, 46) = 1.52$, $p = .22$, $MSE = 0.44$, but they were larger during encoding than during retrieval, $F(1, 46) = 7.61$, $p < .001$, $MSE = 0.09$. Whereas the interaction between experiment and encoding–retrieval was not significant in the analysis of absolute costs, a larger difference between relative memory costs during encoding and relative memory costs during retrieval was revealed for the unrelated word pairs than for the moderately related word pairs, $F(1, 46) = 7.21$, $p = .01$, $MSE = 0.09$. No other effects were significant ($Fs < 1.8$, $ps > .18$).

These results lead to the conclusions that the magnitude and pattern of absolute memory costs are unaffected by changes in the level of FA memory performance but that subtle and sometimes significant differences in the magnitude and pattern of relative memory costs can arise whenever there are differences in FA memory performance. In either absolute or relative terms, DA disrupts encoding but not retrieval. Furthermore, in neither

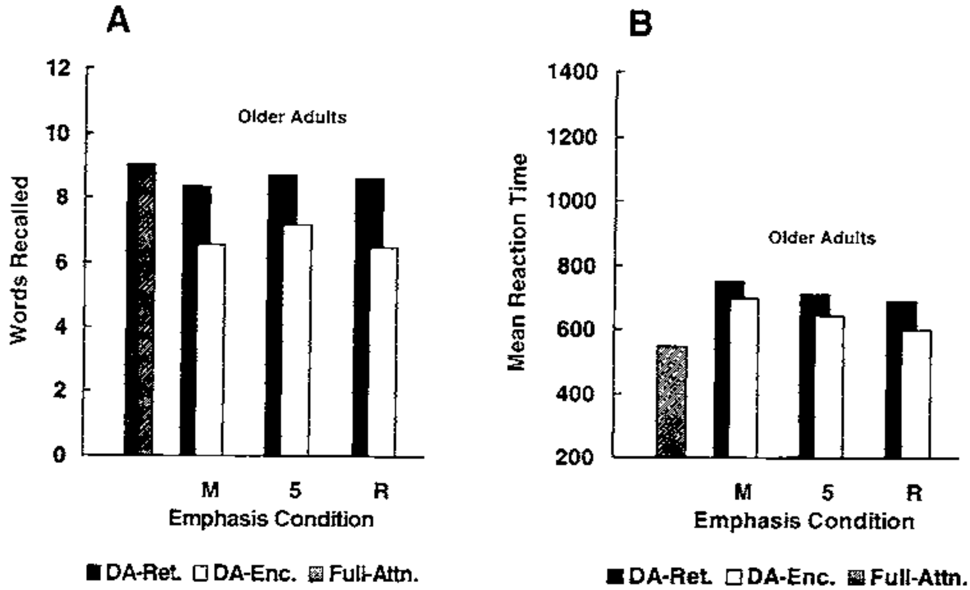

Figure 3. A: Number of words recalled (cued recall) under conditions of full attention (Full-Attn.), divided attention at encoding (DA-Enc.), and divided attention at retrieval (DA-Ret.). Instructions emphasized the memory task (M), the reaction time task (R), or the two tasks equally (5). B: Performance on the reaction time task under full and divided attention conditions (Experiment 3).

the analysis of absolute memory costs nor the analysis of relative memory costs was there a significant effect of the task-emphasis instructions, which supports the case for some age-related reduction in the attentional control of encoding. We return to this issue after presenting the final experiment.

RT costs. Figure 3B shows the mean RTs for the 24 older participants in this study. Relative to single-task RTs, RTs were elevated during both encoding and retrieval, $ts(23) = 6.21$ and 6.78, $ps < .001$, respectively. The moderately related word pairs led to smaller absolute RT costs than did the unrelated word pairs, $F(1, 46) = 6.96$, $p = .01$, $MSE = 58.38$. Absolute RT costs were greater at retrieval than at encoding, $F(1, 46) = 19.26$, $p < .001$, $MSE = 26.08$, for both moderately related and unrelated word pairs (Experiment × Encoding–Retrieval, $F < 1$, $MSE = 26.08$). The reliable effect of task-emphasis instructions on absolute RT costs, $F(2, 92) = 40.96$, $p < .001$, $MSE = 6.95$, was larger for the unrelated word pairs than for the moderately related word pairs, $F(2, 92) = 4.33$, $p = .02$, $MSE = 6.95$. Finally, task emphasis did not interact with encoding–retrieval, and the three-way interaction was not reliable ($Fs < 1$, $MSEs = 7.77$).

The analysis of relative RT costs was perfectly consistent with the analysis of absolute RT costs. Specifically, the moderately related word pairs led to smaller relative RT costs than did the unrelated word pairs, $F(1, 46) = 9.97$, $p = .003$, $MSE = 0.17$, and relative RT costs were larger during retrieval than during encoding, $F(1, 46) = 19.40$, $p < .001$, $MSE = 0.09$. The task-emphasis effect on relative RT costs, $F(2, 92) = 40.91$, $p < .001$, $MSE = 0.03$, was larger for the unrelated word pairs than for the moderately related word pairs, $F(2, 92) = 4.56$, $p = .013$, $MSE = 0.03$. None of the remaining effects on relative RT costs was reliable ($Fs < 1$).

The results from the RT cost analyses confirmed that encoding and retrieval processes were more demanding of attentional resources for older adults. Retrieval operations were particularly resource consuming in the older participants, yet retrieval cues successfully attenuated these demands.

Experiment 4

The goal of Experiment 4 was to examine further the role of retrieval cues in lessening the resource demands of retrieval. Among verbal episodic memory tests, recognition paradigms provide the greatest amount of retrieval support; thus, we predicted that secondary task costs during retrieval should be even further reduced relative to cued recall. Furthermore, age-related differences in these costs were expected to be smaller, and perhaps eliminated, given the supportive nature of the retrieval task.

Method

Participants. Background information on the younger and the older adults is presented in Table 3. The older adults had obtained more years of formal education and performed better on the Mill Hill Vocabulary Scale than did the younger adults, $t(46) = 5.88$ and 7.57, $ps < .001$, respectively, whereas the younger adults performed significantly better than the older adults on the Digit Symbol task, $t(46) = 8.17$, $p < .001$. The two age groups did not differ in their self-reported health ratings, $t(46) = 1.12$, $p = .27$.

Materials and design. The words used in the recognition task were 528 one- to four-syllable common nouns, with an average word frequency of 39 occurrences per million (Kučera & Francis, 1967). Three lists of 26 words were created for practice lists, and one list of 50 words was formed for the response conflict task. For the experimental memory lists, the words were randomly assigned to eight lists of 50 words each,

Table 3
Background Information for Younger and Older Adults Tested in Experiment 4

Variable	Younger		Older	
	M	*SD*	*M*	*SD*
Age	19.7	2.1	68.0	5.2
Education (years)	13.3	0.9	17.1	3.1
Self-reported health	3.4	0.5	3.6	0.5
Mill Hill Vocabulary Scale	17.4	3.3	25.5	4.1
Digit symbol task	71.5	9.7	49.5	8.9

Note. Self-reported health was rated on a scale in which 1 = *poor*, 2 = *fair*, 3 = *good*, and 4 = *excellent*. Mill Hill Vocabulary Scale maximum = 33. Digit symbol scores are the number of correct completions in 90 s.

separately for each version of the materials. Fifteen words from each practice list were selected randomly to serve as targets, and the remaining 11 words from each list served as distractors. For the experimental lists, 30 words were selected randomly to serve as targets, and the remaining 20 words served as distractors.

The recognition test was performed in two phases to prevent manual fatigue in DA at retrieval conditions. The target words were randomly assigned to the two phases of the recognition test, with the restriction that half of the targets (15 words) were presented in each phase. Half of the distractors (10 words) also were presented in each recognition phase, and the order of targets and distractors in each phase was randomly determined. For the practice lists, eight targets and five distractors were presented in one phase of the recognition task, and seven targets and six distractors were presented in the other phase of the recognition task.

Experimental tasks. For the memory task, words were presented auditorily via a cassette player at a 4-s rate, and participants were instructed to form a visual image of each item and to try to make their image as personal or distinctive as possible. The encoding phase was followed immediately by the 30-s interpolated arithmetic task, the first recognition phase, another 30 s of arithmetic, and the second recognition phase. The presentation rate at retrieval was 4 s, and participants were instructed to respond either *yes* or *no* for each word presented in the recognition test to indicate if they recognized the word from the study phase.

Participants also performed the RT task twice, once for 120 s and once for 100 s; these RT task durations matched the duration of the encoding and retrieval phases of the memory task, respectively. The response conflict task was designed to mimic the recognition test: Participants performed the RT task while 25 words were presented auditorily. Half of the participants were instructed to respond *yes* to each word, and half of the participants were instructed to respond *no* to each word. This was followed by 30 s of arithmetic (in which the RT task was not performed) and then by another 25 words to which the participants again responded *yes* or *no* as they performed the RT task.

Procedure. Each participant was tested in two sessions; the total testing time lasted approximately 2.5 hr for the younger adults and 3 hr for the older adults. The younger adults completed the Mill Hill Vocabulary Scale and Digit Symbol test at the end of the first testing session. The older adults started the second session with the Mill Hill Vocabulary Scale and Digit Symbol test. In the second session, all participants received a short warmup RT trial before engaging in the experimental trials. For all participants, the response conflict test was administered halfway through the second testing session.

Results and Discussion

Single-task performance. FA recognition performance (hit rate minus false-alarm rate) was better among the younger ($M = 0.92$, $SD = 0.09$) than the older ($M = 0.85$, $SD = 0.14$) adults, $t(46) = 2.24$, $p = .03$. The mean RTs in FA conditions differed by less than 2 ms between the 120- and the 100-s task duration for both age groups. Thus, the mean of the two task durations served as the single-task RT value, and these were reliably faster for the younger adults ($M = 374$ s, $SD = 39$) than for the older adults ($M = 519$ s, $SD = 67$), $t(46) = 9.15$, $p < .001$. The younger adults' RTs during the response conflict task ($M = 360$, $SD = 33.67$) were reliably faster than were their single-task RTs, $t(23) = 3.56$, $p = .002$. For the older adults, there was no significant difference between their single-task RTs and their RTs during the response conflict task ($M = 520$, $SD = 7$), $t(23) = 0.17$, $p = .87$.[4]

Memory costs. Figure 4A shows the results from the recognition task. As in the previous studies, encoding was considerably disrupted by the secondary task, whereas retrieval was immune to interference from the secondary task. Perhaps the most interesting feature of the recognition data is that the secondary task disrupted encoding more for the younger than the older adults. It also appears that the older adults' memory performance was less affected by task-emphasis effects during encoding than was the younger adults' memory performance.

Encoding was impaired by the secondary task for both age groups, $t(23) = 9.46$, $p < .001$, for the younger adults and $t(23) = 6.44$, $p < .001$, for the older adults; by contrast, retrieval was unaffected by the secondary task, $t(23) = 0.77$, $p = .49$, for the younger adults and $t(23) = 0.99$, $p = .33$, for the older adults. Absolute memory costs were greater for the younger adults than for the older adults, $F(1, 46) = 5.12$, $p = .03$, $MSE = 0.03$, and were greater during encoding than during retrieval, $F(1, 46) = 102.92$, $p < .001$, $MSE = 0.02$. The corresponding age-related effect sizes for the absolute memory costs were −0.57 during encoding and −0.36 during retrieval. Absolute memory costs were sensitive to task-emphasis instructions, $F(2, 92) = 35.63$, $p < .001$, $MSE = 0.01$, but only during encoding, $F(2, 92) = 20.47$, $p < .001$, $MSE = 0.01$, and only for the younger adults, $F(2, 92) = 14.53$, $p < .001$, $MSE = 0.01$. Although the Age Group × Encoding–Retrieval interaction was not significant, $F(1, 46) = 1.26$, $p = .27$, $MSE = 0.02$, it was involved in the significant three-way interaction among age group, encoding–retrieval, and task emphasis, $F(2, 92) = 4.41$, $p = .02$, $MSE = 0.01$. Post hoc tests on this interaction revealed that the absolute memory costs during encoding were comparable for the two age groups when participants were emphasizing the memory task or the two tasks equally; by contrast, the younger adults' absolute memory costs during encoding were larger than those of their older counterparts when the RT task was emphasized. Indeed, task-emphasis instructions during en-

[4] Response conflict RTs for both age groups were faster in this experiment than in the previous experiments. This reduction in RT was probably due to the fact that participants responded either *yes* or *no* to each successive item for the response conflict task in this experiment, whereas participants repeated each word for the response conflict tasks in the previous experiments.

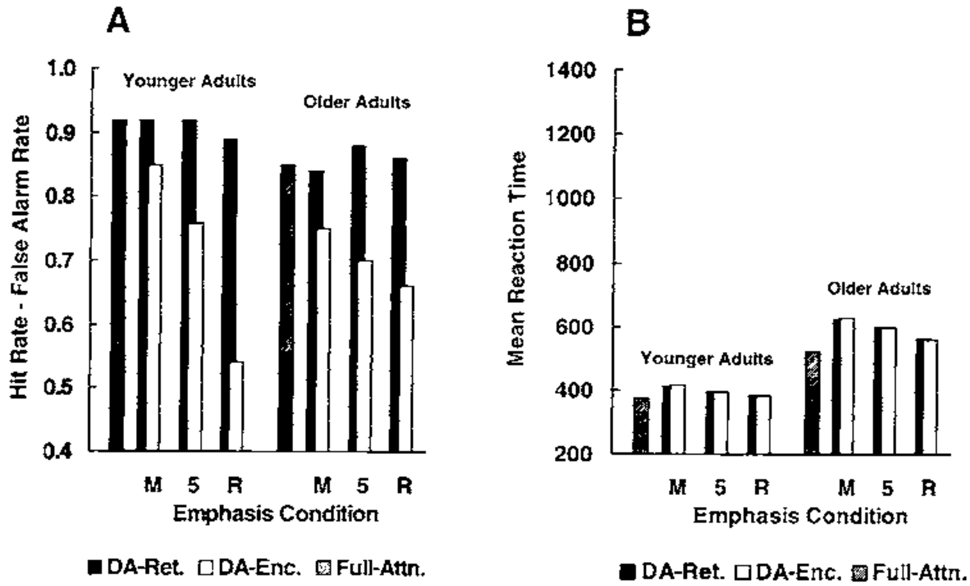

Figure 4. A: Recognition performance (hits minus false alarms) under conditions of full attention (Full-Attn.), divided attention at encoding (DA-Enc.), and divided attention at retrieval (DA-Ret.). Instructions emphasized the memory task (M), the reaction time task (R), or the two tasks equally (5). B: Performance on the reaction time task under full and divided attention conditions (Experiment 4).

coding had no reliable effect on the older adults' memory performance, as was the case in Experiments 2 and 3, although graphically it appears as though the older adults were able to exercise some attentional control of their encoding operations.

The analysis of relative memory costs revealed corresponding effects, although some of the effects that were significant in the analysis of absolute memory costs reached marginal significance only in the analysis of relative memory costs. First, relative memory costs were only marginally larger for the younger adults than for the older adults, $F(1, 46) = 3.36$, $p = .07$, $MSE = 0.03$. Relative memory costs were larger during encoding than during retrieval, $F(1, 46) = 90.18$, $p < .001$, $MSE = 0.03$. In addition, relative memory costs varied as a function of task-emphasis instructions, $F(2, 92) = 32.02$, $p < .001$, $MSE = 0.01$, but only during encoding, $F(2, 92) = 19.02$, $p < .001$, $MSE = 0.02$, and younger adults' relative memory costs were more sensitive to task-emphasis instructions than were those of the older adults, $F(2, 92) = 11.85$, $p < .001$, $MSE = 0.01$. The three-way interaction among age group, encoding–retrieval, and task emphasis that appeared to mediate the other main effects and interactions (see Figure 4A) attained only marginal significance in the analysis of relative memory costs, $F(2, 92) = 2.70$, $p = .07$, $MSE = 0.02$. Note that the power to detect the three-way interaction was lower in the analysis of relative memory costs ($1 - \beta = .52$) than it was in the analysis of absolute memory costs ($1 - \beta = .75$).

These results confirm and extend the results from Experiments 1–3. Memory performance for both age groups was impaired when attention was divided between encoding and a secondary task, but it was maintained at FA levels when the secondary task co-occurred with retrieval. The absolute memory cost results also extend the results from Experiments 2–3 in showing that younger adults did maintain better attentional control of encoding, an issue that is discussed further in the General Discussion section.

RT costs. The mean RT data are shown in Figure 4B, where RTs do not appear to differ between encoding and retrieval for either age group. In addition, the age-related difference in RT costs appears to be much reduced relative to free recall and cued recall. Thus, it appears that the recognition cue did reduce the attentional demands of retrieval, particularly for the older adults.

RTs were slower during encoding and during retrieval than during single-task conditions for both age groups, $ts(23) = 3.41$ and 4.42, $ps = .002$ and $< .001$, during encoding and $ts(23) = 3.08$ and 6.08, $ps = .005$ and $< .001$, during retrieval for the younger and older adults, respectively. The analysis of absolute RT costs revealed an age-related increase in the magnitude of RT costs, $F(1, 46) = 14.32$, $p < .001$, $MSE = 13.74$. Absolute RT costs did not differ between encoding and retrieval for either age group ($Fs < 1$, $p > .85$, $MSE = 67.01$). The corresponding age-related RT effect sizes were .74 during encoding and .93 during retrieval. Absolute RT costs were sensitive to the task-emphasis instructions, $F(2, 92) = 36.79$, $p < .001$, $MSE = 15.63$, particularly for the older adults, $F(2, 92) = 4.20$, $p = .02$, $MSE = 15.63$. No other effects reached statistical significance ($Fs < 1$).

The relative RT costs largely confirmed the results from the absolute RT costs. That is, relative RT costs were significantly greater than zero during encoding, $t(23) = 3.61$, $p < .001$, for the younger adults and $t(23) = 4.52$, $p < .001$, for the older adults, and during retrieval, $t(23) = 3.25$, $p = .003$, for the younger adults and $t(23) = 6.39$, $p < .001$, for the older adults. The $2 \times 2 \times 3$ ANOVA revealed that relative RT costs were larger among the older adults than among the younger adults, $F(1, 46) = 9.57$, $p = .003$, $MSE = 0.05$, but did not differ between encoding and retrieval for either age group ($Fs < 1$, $MSE = 0.03$). Relative RT costs did vary as a function of the task-emphasis instructions, $F(2, 92) = 42.76$, $p < .001$, $MSE = 0.01$; however, in contrast to the analysis of absolute RT costs, the relative RT costs of the younger and the older adults did not differ in their sensitivity to the task-emphasis instructions. Finally, as in the analysis of the absolute RT costs, the interaction between encoding–retrieval and task emphasis, and the three-way interaction among age group, encoding–retrieval, and task emphasis, were not reliable ($Fs < 1.10$, $MSE = 0.004$).

Once again, RT costs were greater among the older adults relative to their younger counterparts, but the RT costs for the older age group were much reduced at retrieval relative to free and cued recall. Thus, we conclude that supportive retrieval environments do successfully attenuate age-related increases in the attentional demands of retrieval.

General Discussion

The primary goal of these experiments was to investigate age-related differences in the effects of DA on encoding and retrieval operations, about which four main conclusions can be drawn. First, encoding was disrupted by the secondary task, and, on balance, DA during encoding resulted in similar costs to memory performance for the younger and older adults. Second, encoding was associated with greater secondary task costs among the older than the younger adults. These results suggest that for both age groups, controlled organizational and mnemonic strategies demand attention and that these operations can be disrupted by a secondary task. Third, for neither age group was memory performance disrupted in cued recall or recognition when the secondary task was performed during retrieval. In free recall, the decrements in memory performance attributable to DA during retrieval were reliable only in terms of absolute costs for the younger adults, but even these were still much smaller than those observed during encoding. Fourth, despite the general conclusion that DA during retrieval does not impair memory performance for either younger or older adults, there was an age-related increase in secondary task costs during retrieval. This increase in RT costs during retrieval implies that retrieval makes greater demands on attentional resources for older than younger adults. It does not appear to be the case that the older adults' increased attentional demands of retrieval are associated with increased response production costs: the older adults' RTs during the response conflict task (when participants were speaking a word without any memory retrieval requirements) were sometimes slower than and sometimes did not differ from their single-task RTs. More important, however, is that even if response production is more resource demanding for older than younger adults, the small amount of time attributable to those resource demands (never more than 70 ms) comes nowhere near to accounting for the age-related increases in the attentional demands of retrieval.

Inspection of Figures 1–4 suggests that RT costs during retrieval declined from free recall, to cued recall, to recognition, particularly for the older adults. This fact was confirmed by 3 × 2 × 2 ANOVAs conducted separately on absolute and relative RT costs (averaging over task-emphasis conditions), with experiment (Experiment 1 free recall, Experiment 2 cued recall, and Experiment 4 recognition) and age group between subjects and encoding–retrieval within subjects. All main effects and interactions were significant at the .001 level. Post hoc tests conducted on the three-way interaction among experiment, age group, and encoding–retrieval revealed three particularly interesting facts: (a) Absolute RT costs during encoding did not differ across experiments for either age group, and relative RT costs during encoding differed only for the older adults between free recall and recognition. (b) Absolute and relative RT costs during retrieval were significantly larger during free recall than during cued recall and were in turn larger during cued recall than during recognition for the older adults, whereas only the difference between free and cued recall was significant for the younger adults. (c) Age-related increases in absolute and relative RT costs at retrieval were larger during free and cued recall than during recognition. Recall that the effect size for the age-related differences in RT costs during retrieval was largest in cued recall, smaller in free recall, and smallest in recognition. Despite the difference between the results from the ANOVA and the rank order of the effect sizes, both analyses support the conclusion that recognition makes fewer demands on attentional resources than does recall, particularly for older adults.

Note that the data from the younger adults in these studies almost perfectly replicated those presented by Craik et al. (1996) despite the fact that there were several procedural differences between the two sets of studies. The first major procedural change was to the RT task. In the current studies, the visual stimuli for the RT task were prominent and bright, and participants provided a manual response on an external keyboard. In the studies reported by Craik et al., the visual stimuli for the RT task were small asterisks, and participants provided a manual response on a standard computer keyboard. Accuracy also was recorded for the RT task in the current experiments; in the studies reported by Craik et al., errors were not recorded but were reflected as long RTs for the next correct buttonpress. The second major change was the instruction to use mnemonic strategies in the current experiments. Comparing the current data with those reported by Craik et al., it appears that strategies elevated performance uniformly but did not alter the pattern of data. The similarity of these results to those presented by Craik et al. speak to the reliability of our findings.

Our data also provide further evidence for the independence of attentional resources and attentional control. Looking at the data from the younger adults first, memory performance was modulated by the task-emphasis instructions during encoding, but not during retrieval (but see those for free recall). Furthermore, both encoding and retrieval were associated with secondary task costs. These results generally concur with those of Craik et al. (1996) and bolster the conclusion that encoding operations consume attentional resources and are under attentional control but that retrieval processes operate outside of attentional control, yet nevertheless demand attention. Encoding and retrieval produced larger secondary task costs for the older than the younger adults, suggesting that these operations require greater attentional resources as people age. In addition, there was some evidence for reduced attentional control of encoding among the older adults. In cued recall (Experiments 2 and 3) the older adults showed reduced effects of task-emphasis instructions on their memory performance, and in recognition (Experiment 4) the older adults' memory performance was not affected significantly by task-emphasis instructions during encoding. Two explanations for these findings can be rejected outright. First, the older adults were not "protecting" their memory performance because, in these same experiments, their RTs during encoding were highly sensitive to task-emphasis instructions. Second, floor effects in memory performance did not contribute to these findings, because the older adults in Experiments 3 and 4 did not demonstrate a reliable task-emphasis effect, even though their memory performance was high. We therefore suggest that, in at least some cases, older adults demonstrate less attentional control of encoding operations. Although this conclusion is inconsistent with the findings from other tasks (e.g., Salthouse et al., 1984), it is consistent with the suggestion that aging is associated with reductions in consciously controlled processes (Hasher & Zacks, 1979; Jacoby et al., 1989; J. M. Jennings & Jacoby, 1993).

The dissociation between attentional control and attentional resources is not easily accommodated by the notion of a single pool of attentional resources, because that idea assumes that attentional control behaviors such as selectivity exist to allocate the limited resources effectively among competing resource-demanding tasks (e.g., Broadbent, 1958; Norman & Bobrow, 1975). A single-resource model would predict a trade-off relationship between memory costs and secondary task costs, yet in the current studies the average correlation between these measures was only −.02 for the younger adults and −.10 for the older adults, and only 4 of the 42 correlations reached significance. Similar findings were reported by Craik et al. (1996).

The dissociation between attentional control and attentional resources suggests that there is more than one determinant of DA effects. Jacoby (1991) has proposed that two independent processes are involved in memory, one controlled and one automatic. Using the process dissociation procedure, Jacoby has shown that controlled processes are reduced in advanced age and by DA, whereas automatic processes are spared by both factors (Jacoby, 1991; Jacoby et al., 1989; J. M. Jennings & Jacoby, 1993). The remember–know paradigm developed by Gardiner and colleagues (e.g., Gardiner & Parkin, 1990) reveals corresponding results, in that aging and DA reduce conscious remembrance of the study episode but leave familiarity-based "know" judgments unaffected. However, it is difficult to interpret our data in either of these terms. According to these paradigms, only automatic or familiarity-based processes are operating under DA conditions, yet there does not seem to be a ready explanation for why these automatic processes or familiarity-driven judgments come at a substantial cost to a secondary task or why the secondary task costs associated with a familiarity-based process would vary substantially as a function of the memory paradigm used.

Whereas the notion of automatic and controlled processes is clearly important, we believe that the dissociation can be better understood in terms of a neuropsychological model. As outlined in the introduction, Moscovitch's (1992; Moscovitch & Umilta, 1990, 1991) working-with-memory model proposes two major components involved in memory: a strategic frontal system that controls encoding and retrieval operations and a modular MTLH component that passively stores information before consolidation. The working-with-memory model asserts that a secondary task disrupts the activities only of the frontal component (Moscovitch, 1994). The contents of the MTLH, on the other hand, can be disrupted only by other information in the MTLH, as occurs in proactive and retroactive interference.

The working-with-memory model provides a reasonable explanation of memory costs in a DA paradigm, but it does not directly address the source of RT costs. According to the model, memory costs during encoding arise because a secondary task interferes with controlled encoding processes, thereby compromising the information submitted to the MTLH component, resulting ultimately in impaired memory performance relative to FA conditions. Results from positron emission tomography (PET) studies have corroborated Moscovitch's assertion, in that a concurrent task during encoding does result in reductions in frontal lobe activation (Fletcher et al., 1995; Shallice et al., 1994). By contrast, retrieval from the MTLH is automatic, given that proper retrieval cues are provided or generated by the individual. Accordingly, memory performance is essentially immune to disruption under conditions of DA during retrieval in cued-recall and recognition paradigms. The frontal lobe system is responsible for the generation of retrieval cues when they are not provided by the retrieval environment, as is the case in a free-recall paradigm, and for the evaluation and organization of the information received from the MTLH. Consistent with these ideas, reliable costs to memory performance are observed under conditions of DA during retrieval in a free-recall paradigm (Experiment 1 in absolute costs for the younger adults; Craik et al., 1996; Park et al., 1989). It also is reasonable to suggest that DA at retrieval might reduce the frontal system's efficiency at evaluating the information retrieved from the MTLH, and Baddeley et al. (1984) did find longer retrieval latencies during conditions of DA at retrieval than in FA conditions.

Although the working-with-memory model does not attempt to account for secondary task costs in a DA paradigm, two explanations are plausible: First, RT costs could reflect the efficiency of the frontal lobe system in generating retrieval cues and in evaluating the output of the MTLH before response output. According to this account, the older adults' larger RT costs reflect a less efficient frontal lobe system. The frontal lobes have been found to be preferentially affected by aging in terms of reductions in volume and reduced regional blood flow (Coffey et al., 1992; Gur, Gur, Obrist, Skolnick, & Reivich, 1987; Haug et al., 1983). Also, Cabeza et al. (1997) found in a PET study that, relative to younger adults, older adults show reduced activation of the frontal lobe areas associated with encoding and retrieval, combined with activation of other frontal lobe areas during retrieval that are not typically activated in younger adults. These preliminary neuroimaging data thus provide overall support for the notion of decreased efficiency of encoding and retrieval in older adults (see also Schacter, Savage, Alpert, Rauch, & Albert, 1996, for additional PET evidence of less efficient retrieval among older adults). Age-related changes in neurophysiology and neural activity certainly have corresponding functional effects, and older adults do perform more poorly than younger adults on many tests that are thought to be sensitive to frontal lobe functioning (for reviews, see Albert & Kaplan, 1980; Moscovitch & Winocur, 1992, 1995). Thus, the first proposal is that increased secondary task costs during encoding and retrieval reflect inefficient strategic frontal functioning among older adults.

The second plausible explanation for RT costs is based on a merger of the working-with-memory model with Pashler's (1994; Carrier & Pashler, 1995) work on the psychological refractory period. Specifically, if retrieval from the MTLH is automatic once a retrieval cue is provided or is generated internally (as the working-with-memory model suggests), and if response selection on a secondary task cannot be initiated until memory retrieval is complete (as Carrier & Pashler, 1995, found), then secondary task RTs might reflect the time needed to retrieve information from the MTLH. Like many brain regions, the hippocampus is vulnerable to the aging process (Golomb et al., 1993; Meencke, Ferszt, Gertz, & Cervós-Navarro, 1983), and one would expect that age-related impairments of the MTLH would contribute to memory decrements in older age (for PET evidence, see Grady et al., 1995, but see Schacter et al., 1996). Thus, this second suggestion is that the older adults' RT costs are larger than the younger adults' because response selection on the secondary task cannot be initiated until retrieval from the MTLH is completed (i.e., during encoding to detect new information or during retrieval to produce a desired memorandum), a process that may take longer in advanced age.

Further research is clearly warranted to tease apart these two explanations for secondary task RT costs. It is probably true that structural and functional changes to both the frontal lobes and to the MTLH contribute to memory performance decrements with aging, but the question is, Which component contributes to larger RT costs for older adults? In any event, both causes of age-related increases in secondary task costs can be said to reflect increased attentional demands of mnemonic operations, in the first case because of reduced efficiency of encoding and retrieval operations and in the second case because of slower operations in the MTLH.

Finally, although our results replicate those of Baddeley et al. (1986), Light and Prull (1995), Nyberg et al. (1997), and Park et al. (1986, 1987) in finding comparable memory costs during encoding among younger and older adults, we reiterate that Park et al. (1989) and Salthouse et al. (1984) did find an age-related increase in the effects of DA on memory performance. Park et al. (1989) used a digit-monitoring secondary task in which participants heard two-digit numbers and had to press a button whenever they heard an odd number. According to the working-with-memory model, conscious apprehension of the number would automatically engage the MTLH, and the MTLH would probably play a role in recalling whether the digit is odd or even. Similarly, in the study conducted by Salthouse et al. (1984), participants simultaneously encoded and retrieved two lists, a paradigm that likely would cause interference in the MTLH. Age-related cell loss in the hippocampus may make older adults more susceptible to MTLH interference. This discussion leads to the interesting prediction that age-related differences in memory costs may appear when there is interference among information in the MTLH.

In conclusion, our data provide clear and compelling evidence that, whereas strategic encoding and retrieval processes are no more disrupted by concurrent activity in older than younger adults (at least when strategy instructions are provided), these mnemonic operations do place greater demands on the older adults' attentional resources. The data also shed more light on the dissociation between attentional control and attentional resources: Resources may be the necessary fuel for complex cognitive processes, only some of which operate under attentional control. Our findings suggest that encoding and retrieval operations appear to demand more attentional resources for older than younger adults and that older adults are apparently less able to exercise attentional control over their encoding processes. Finally, our results illustrate the fact that supportive retrieval environments attenuate age-related increases in the attentional demands of retrieval.

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